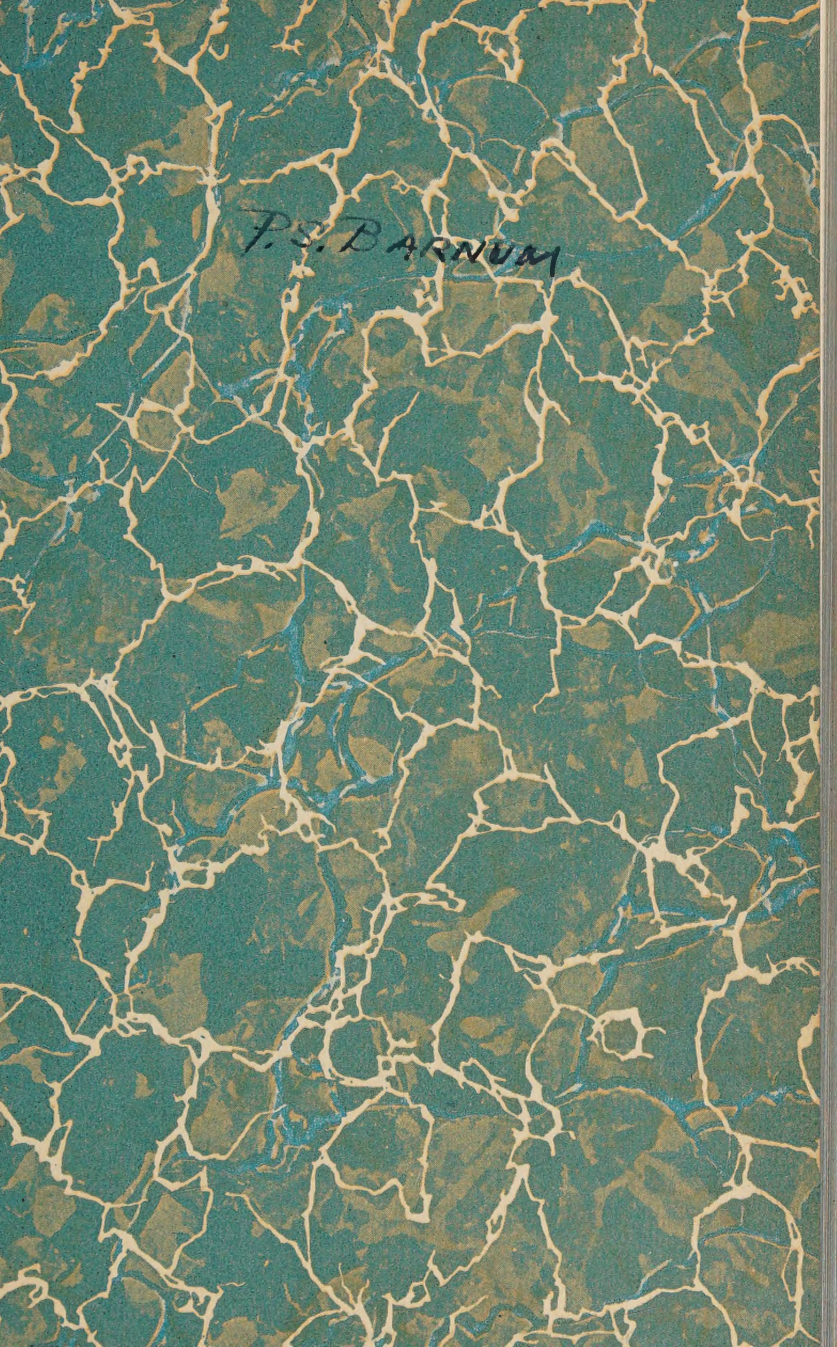






F. S. BARNUM



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Manufacture of Steel

By

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MANUFACTURE OF STEEL

Parts 1-4

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MANUFACTURE OF STEEL

Serial 2053A

(PART 1)

Edition 1

INTRODUCTORY

1. Definition of Steel.—While at first thought it seems to be a simple matter to define steel properly, the more familiar one becomes with the subject, the more perplexing it is to write a concise definition that will apply to the wide range of steel produced, or even to the greater part of them. Before the introduction of the modern methods of manufacture, the distinction between steel and wrought iron was sharp and well marked, and steel could then be defined as “any alloy of iron with carbon that would take a temper on quenching.” Wrought iron does not sensibly harden on sudden cooling in water from a red heat. Modern methods of steel manufacture, however, can produce either a metal that partakes largely of the nature of wrought iron, or else one that hardens on quenching. For this reason such a classification as the above would now throw out the greater amount, or at least a very large tonnage, of the material classed and accepted by the metallurgical and commercial world as steel. The Bessemer converter and open-hearth furnace early showed an adaptability to produce a soft metal having great strength, elasticity, and ductility, capable of displacing wrought iron, and, for most purposes, far superior to it. Anything that follows is not offered as a thoroughly comprehensive definition of steel, as none can be offered that is not easily assailable and its inapplicability shown from some standpoint.

Steel may be described as a metal produced by the complete fusion of materials in a bath, the necessary properties being given, after conversion, by additions of carbon or carbon alloys. Wrought iron may be described as a metal produced by the partial fusion, or bringing to a pasty condition, of materials on a hearth.

"Blister," or "cementation," steel, made by soaking bars of iron, at or above a red heat, in charcoal or carbon, would seem to be a notable exception; but as this is mainly an intermediate product for remelting in crucibles, and its production being of little importance, it will be disregarded in this treatment of the subject.

2. The question of the proper classification of steels is one to which much attention has been given in the past, an international committee at one time having been selected from the metallurgical and technical societies of the principal steel-producing countries to adopt a universal classification. While much good came of their work and strenuous efforts were made to adopt their classification, it was never used generally metallurgically nor commercially.

Many theories have been advanced as to what steel is. One that is held by many practical metallurgists is that the ideal steel is an alloy of pure iron and carbon only, all other elements being regarded as impurities. From this point of view all grades of steel can be produced simply by varying the amount of carbon; but as impurities are necessarily present, all steels contain varying, and usually very small, amounts of sulphur, phosphorus, silicon, metallic oxides, and gases, which require other additions for their neutralization or elimination. Again, special alloys are required for giving steels characteristic qualities for particular purposes; such are the nickel, tungsten, chrome, manganese, and molybdenum steel.

3. **History.**—Steel was probably first made in Asia or Northern Africa by the Chaldeans, Egyptians, or other early civilizations, by methods probably more like the crucible process than any we have record of today. In fact, a very

limited amount of steel, but of most excellent quality, is still made in India (called Indian or Wootz steel) by reducing very pure ores, mixed with chopped wood, in clay crucibles heated by a charcoal fire blown by goatskin bellows. From this steel the celebrated Indian sword blades were made, than which no finer tool steel has ever been produced.

Our interest in present methods of manufacture dates from the invention of the crucible process, in 1740, by Benjamin Huntsman, of Sheffield, England, a clockmaker dissatisfied with the quality of cementation steel in clock springs. This remained practically the only method of production for over a century, when in 1855 the Bessemer process was invented by Henry Bessemer and the regenerative open-hearth furnace by the Messrs. Charles William and Frederick Siemens in 1861. Not until these processes, especially the Bessemer, had produced large quantities of steel much cheaper than the crucible, did steel begin to supplant wrought iron to any great extent and thereby inaugurate the *age of steel*. It is this vast tonnage of cheap steel that has rendered possible the wonderful industrial development of the world in railroad and ship building, the varied lines of engineering and construction affecting every nation of the world and the condition of each individual.

4. Processes of Manufacture.—There are four processes for the manufacture of steel: The crucible, the oldest of present methods; the Bessemer; the open-hearth, and the electric. The Bessemer was the second process perfected, and for the first 30 years, or up to about 1890, led the open-hearth, both as to tonnage produced and in the perfection of methods and appliances—both metallurgical and mechanical. While the Bessemer process still produces the greater tonnage per furnace, this is the only direction in which it can claim superiority over the open-hearth. In the order of their metallurgical and commercial importance today the processes rank in America, as follows: First, the basic open-hearth; second, the Bessemer; third, the acid open-hearth; fourth, the electric; and fifth, the crucible. The basic Bessemer process is

important in England and Europe, but is not used in America.

It should be emphasized at this point that the importance of a steel process depends upon: First, available raw materials; and second, quality of product. The acid Bessemer process maintained its supremacy in America as long as iron ores low enough in phosphorus held out at low prices. But the gradual exhaustion of low-phosphorus ores (Bessemer ores, see *Manufacture of Iron*) boosted the price of Bessemer pig iron to that point where commercial advantages of the process were overcome by the relatively higher price of its material for conversion. The Bessemer process is quicker, much cheaper to operate, gives a larger output at smaller installation cost, has greater flexibility in respect to output tonnage and output chemical analysis. The quality of its product, however, is not quite so good, and the raw material it requires costs much more than that needed for the basic open-hearth process. Therefore, its chief importance today is in combination with the basic open-hearth process, as one of the so-called *duplex processes*, in which the raw material is phosphoriferous pig iron. The Bessemer process is utilized to remove the impurities quickly from the pig iron, but the final purification takes place in the basic open-hearth furnace. Another duplex process is carried on in the Bessemer converter, followed by a super-refining in the electric furnace.

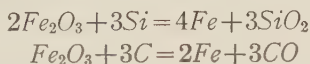
The electric and the crucible processes produce the highest grades of steel, chiefly on account of their ability to produce a *dead melted* steel—that is, one from which the gases and oxides have been largely eliminated. These steels are, therefore, used for high-grade cutting tools: chisels, drills, lathes, and other machine tools, cutlery, important parts of automobiles, and other machinery, special wire and similar purposes for which one can afford to pay the extra price which the relatively higher cost of these two processes warrants. The electric process has at present sales advantages in respect to talking points, but probably does not produce a steel superior to crucible steel. The fact that electric steel can be produced a little cheaper, makes manufacturers prefer to sell

it, and the reputation of crucible steel has been hurt in America by the use of inferior raw materials—steel cuttings instead of the best wrought iron, etc.

The Bessemer process still produces a large tonnage of railroad rails, wire, and steel pipe, because its quality is suitable for these purposes. Its type of operation fits in well with the rolling processes for rails, wire rods, and skelp (for pipe); and there is much capital invested in Bessemer plants doing this work. The basic open-hearth process has, however, driven the Bessemer out of most of the other big fields, and is encroaching rapidly on the tin-plate and small-structural-shapes fields. Wherever a steel low in phosphorus is required, a basic process is used, that is, a process using basic slag.

THE OPEN-HEARTH PROCESS

5. Historical.—Steel was first made by the open-hearth process in England in 1862, in the regenerative furnace of the Siemens brothers, which was patented in 1861, but which was developed and perfected by Charles William Siemens, who is better known by his title, Sir William. This was not the first attempt to make steel on an open hearth, however, many previous experiments having been made, notably those by Josiah Marshall Heath, in 1845. But it was only with the Siemens regenerative apparatus, which gives a high temperature together with excellent heat control, that success was possible. Siemens' efforts were originally directed to producing steel by the reduction of iron ore in a bath of pig iron. The ore furnished oxygen for oxidizing the carbon, silicon, and manganese of the pig metal and a corresponding amount of iron was reduced and the yield thereby increased. The chemical equations representing the reactions taking place between the ore and the silicon and carbon are written:



About 1864 the Messrs. Martin, French steel makers, made steel by melting pig iron and scrap in the Siemens furnace,

and they patented the process. In France and some parts of Europe it is still known as the Martin-Siemens, or Martin, process, but in Great Britain and America as the Siemens-Martin, or more generally in recent years merely as the open-hearth process. The above terms are used indiscriminately, but it should be clearly understood that the Martins never laid claim to the regenerative furnace, but only to the pig-and-scrap process worked in the Siemens furnace, for which entire credit is due them, while the furnace is wholly a Siemens production. It is correct to speak of the Siemens-Martin process (pig and scrap), but only of the Siemens furnace.

The pig-and-ore and the pig-and-scrap processes have for years been used in combination. Some times, and in some localities, the amount of available scrap is so reduced that metallurgists find it cheaper to use the pig-and-ore process of which the two most successful methods will be considered in detail.

6. Open-Hearth Furnace.—The open-hearth furnace consists of a rectangular hearth two or three times as long as it is wide; the term *open* simply signifies that the hearth is so constructed at both ends. This form is one of the oldest of metallurgical furnaces, and it is also called a reverberatory furnace, but the regenerative principle of the Messrs. Siemens constitutes its originality and value in connection with steel manufacture. By *regeneration* is meant the giving up of the waste heat of the escaping gases and the temporary storing of it in brickwork from which it is given out again to the air for combustion, which is thus always preheated, or regenerated. By this means a very much higher temperature than is otherwise possible is obtained, as well as great fuel economy. Theoretically, the only limit to the temperature attainable in a regenerative furnace is the point of dissociation of hydrogen and oxygen, about $2,500^{\circ}\text{C}$. ($4,532^{\circ}\text{F}$). This point, however, can never even be approximated practically, owing to the limit set by the inability of the refractory materials to withstand such a temperature and the rapid loss of heat by radiation at high temperatures.

7. Construction of the Open-Hearth Furnace.—Two types of furnaces are in general use: The fixed, or stationary, furnace and the tilting, or rolling, furnace. In both types the furnace proper, or melting chamber, is the same—rectangular in section and connected with regenerators, as has been explained. It is covered with an arched roof of 9 or 12 inches of the best grade of silica brick; the side walls are also made of the same material, usually 9 inches thick. Silica bricks expand, about $\frac{1}{4}$ inch to the foot in heating to a working temperature, and to allow partly for this, they are never laid close. Further allowance for this expansion is made in the construction by a system of tie-rods having turn-buckles, or nuts, so that they can be lengthened as the furnace heats and the bricks expand.

The hearth is built in a pan of heavy riveted plate steel carried on beams supported on a solid block of concrete and brick, or on heavy foundation walls, or piers, so that the weight of the furnace and charge is not carried on the regenerator arches, if these are under the furnace. The approved construction is to place them under the working platform. Other beams are set perpendicularly along the sides and ends, their ends connected beneath and above the furnace by tie-rods. These beams, called *buck-stays*, are connected by means of tie-rods at the top and bottom and serve to keep the furnace sufficiently rigid. Without these the structure would not stand the strain of the weight of the charge and the expansion and contraction as the temperature changes.

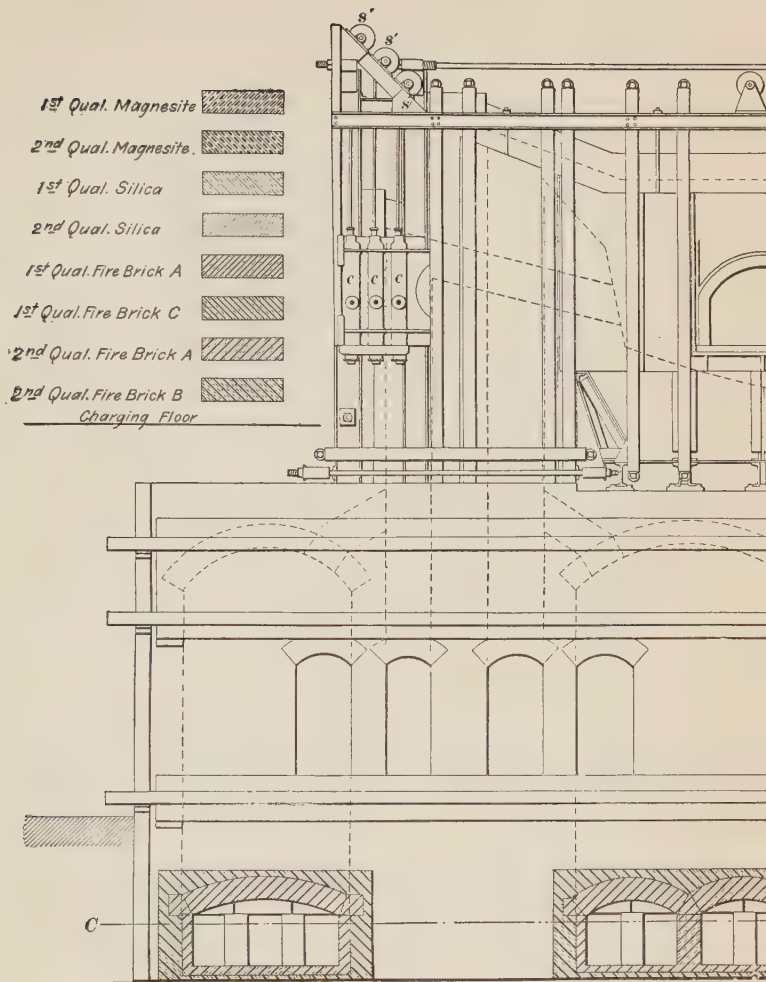
8. Roof.—For many years the roof of the furnace was thrown from the side walls; that is, the weight of the roof was carried by the walls, just as the weight of any arch is carried on the walls from which it springs. This construction was objectionable for many reasons, and caused serious trouble when the side walls of the furnace prematurely cut out, as frequently happens. In such cases it was practically impossible to repair the walls, and the weight of the roof soon caused them to fall. The side thrust on the walls also caused their distortion, and, as they wore down, this became more

serious. The present method of construction obviates these objections by carrying the roof on heavy channels, in which the skew back (the beveled brick on which the arch starts) is placed so that almost the entire weight of the roof is carried by the two channels, thus relieving the walls. In this way when the side walls fall in or are partly burned out, they may readily be renewed or patched without disturbing the roof. Or at the end of a run, if the roof is in good condition, other repairs necessary may be made and the old roof used for the next run. This is not general practice, as it is customary at most plants to put on a new roof for each run of a furnace.

While the construction of basic open-hearth furnaces varies greatly, a stationary furnace is shown in Figs. 1 and 2. Fig. 1 is a longitudinal section of the right-hand half through the center and a side elevation of the left-hand half. Fig. 2 (*a*) is a cross-section on the line *AB* of Fig. 1. These figures illustrate a common form and show the principle of all open-hearth construction.

9. Siemens Regenerator.—The air and gas chambers are built of the same length and height and extend at right angles to the furnace hearth. The air chambers are about one and one-third times the width of the gas chambers, a greater volume of air being required than of gas. Both chambers contain checkerwork of brick, usually the best quality firebrick or silica, so laid as to expose a large surface to the gases. Sometimes the construction is such as to give a number of small horizontal flues in each chamber, but more generally the brick are staggered in or baffled, alternate courses being placed over the parallel passage below, in both horizontal and transverse courses. This is done to distribute the current of waste gases and bring them more intimately into contact with the brick surfaces of the checkers, assuring a better absorption of heat and, in turn, a more thorough reabsorption of this stored heat by the incoming gas and air when the currents are reversed.

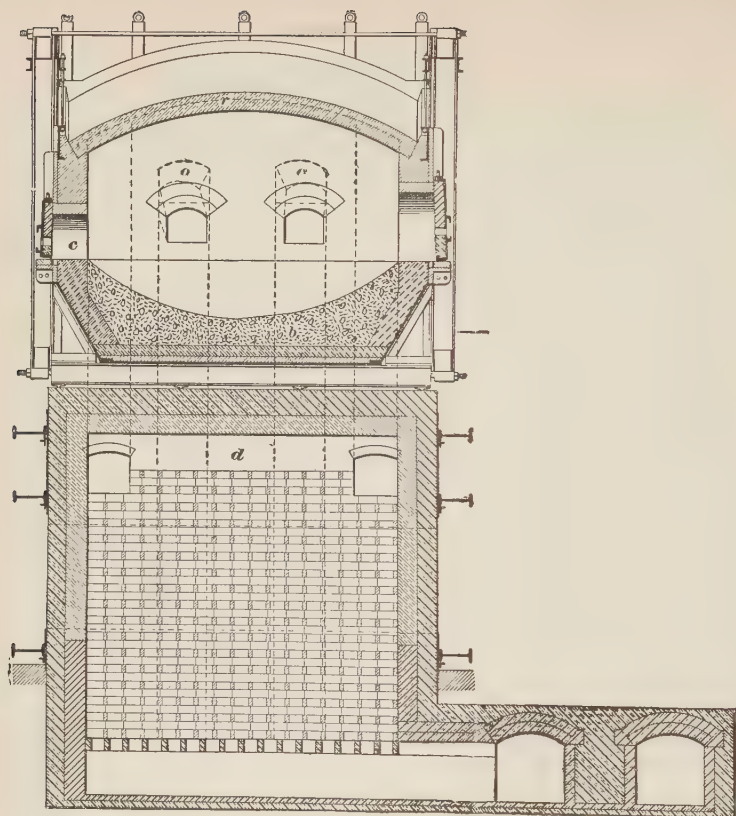
In Fig. 1, *a* and *g* show, respectively, the air and gas chambers on one end containing the brick checkerwork (the oppo-



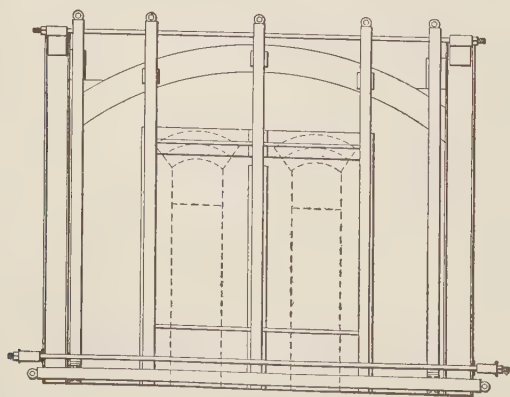
site end is exactly the same, but the chambers are not shown); from the chambers the vertical flues, or uptakes u_a , u_g , lead to the ports p_a , p_g , the air being carried above the gas; on the other side of the furnace, at the same end, are corresponding flues leading from the opposite end of the air and gas chambers, so that on each end of the furnace there are two air uptakes and ports and two gas uptakes and ports. Frequently one large gas uptake leads from the middle of the gas chamber, terminating in one port between the air ports. The simplest way to understand the relations and functions of the chambers and ports is to consider them as parts of one huge gas burner; the supply of gas and air comes from the respective chambers and is conducted by the tubes (uptakes and ports) to where they can mix and combustion take place, that is, in the melting chamber, where the heat is wanted. The bottom, or hearth, is shown at b . The roof is made of 9-inch or 12-inch silica brick, 9-inch in this case. The flues f under the checkerwork connect them with the valves and draft stack. The slag pockets s extend under a part or all of the furnace; they are a continuation downwards of the uptakes, their purpose being to catch any slag, brick, etc. and keep it out of the chambers.

The left-hand section of Fig. 1 shows the elevation from the top of the furnace to the bottom of the chambers; also the beams, tie-rods, etc. for supporting and strengthening the structure. The hydraulic, or pneumatic, cylinders c , c are for raising and lowering the furnace doors by means of chains passing over the sheaves s' , s' , s' ; they are controlled by valves conveniently placed on the charging floor.

Fig. 2 (a) is a cross-section through the hearth of the furnace on the line AB of Fig. 1. Fig. 2 (b) is an end elevation of the furnace. Fig. 3 (a) shows a horizontal section of the flues on the line CD of Fig. 1. It shows the flues a and g with their connections a' and g' to the air and gas valves v_a and v_g , for one end of the furnace and to the stack. The dampers in the chamber and stack flues are shown at d . Fig. 3 (b) is a section on the line GH , showing the air and gas reversing valves v_a and v_g , and the regulating valves v for each.



(a)



(b)

FIG. 2

Tracing the course of the gas and air, we have the gas and air entering through the valves, thence through the flues to the chambers shown in Figs. 2 and 3; the uptakes and ports now conduct it to the melting chamber for combustion; the waste gases passing out at the opposite end through the chambers and flues to the stack. At the end of 15 minutes the reversing valves are thrown and the gas and air pass in the opposite direction. This reversal at regular intervals of the current is continued throughout the working of the furnace. There is no mixing of the gas and air until they are brought together at one end of the hearth for combustion. It sometimes happens that a communication is previously established between them by the cutting through or wearing away of a division wall, when premature combustion takes place—the gas always being hot enough to burn readily after passing a very short distance through the chamber. In such a case the hearth is robbed of just that amount of heat besides the serious injury to a part of the furnace not designed or capable of withstanding the temperature produced.

As the gas and air first enter the hot regenerators, the latter are cooled, as no heat is produced until the gas and air meet in combustion in the furnace beyond. The flame here begins to heat the furnace and also the regenerators at the other end, as the waste gases pass through on their way to the stack. When the chambers, on the end at which the gas and air enter, are cooled somewhat and those on the opposite end correspondingly heated, the reversing valves are thrown so that the gas and air travel in the opposite direction. By this means the regenerators are constantly becoming hotter, so that the heat produced by the combustion of the gases is a continually increasing quantity—a thermal arithmetical progression. The hotter the gas and air (within limits here attainable), the higher is the temperature they produce on combustion. The regular reversal of the gases, which by going through the regenerators and becoming constantly hotter, produces a constant increment of temperature in the melting chamber. This is so great

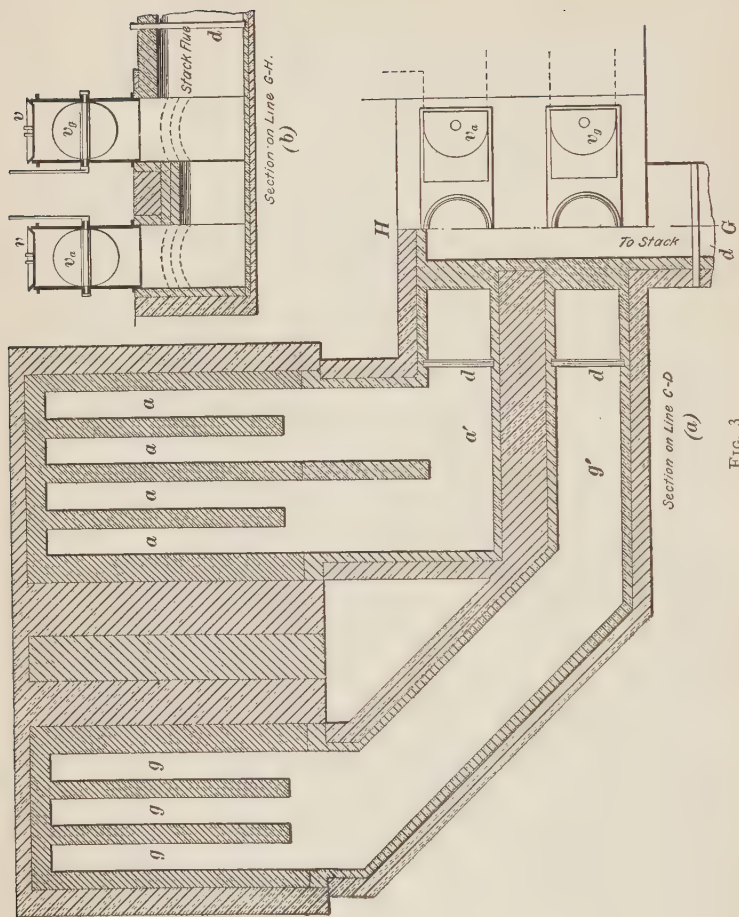


FIG. 3

that without the careful regulation of gas and air a furnace would *melt itself down* in a short time. This is especially true in an empty furnace, or toward the end of a heat when the stock is all melted and the metal hot. Such a condition can scarcely come about during the melting-down stage as the bath is then rapidly absorbing heat.

10. Ports.—The ports are the openings or passages through which the gas and air are led into the furnace hearth, combustion taking place at their mouths. They are connected with the regenerative chambers by what are commonly termed the *uptakes*. There is no part of the furnace requiring greater care in design and construction, for there is no doubt but that proper combustion depends more on their size, proportion, and arrangement than on any other point.

There are usually two gas and two air ports at each end of the furnace. This is varied by two gas and three air or one gas and two air, the air in any arrangement always being on the outside and above the gas, because the air is the heavier, and, by having it on top of the gas as the two spread out and mix at the port ends, combustion takes place, and the flame is thrown toward the bath. By this means not only is the heat kept on the stock or bath, but the cutting action, aside from or in connection with, the temperature produced has much to do with the melting down of the stock. An important point is to keep the flame away from the roof, as the latter may cut out or be melted down with improper port design. Another reason for having the air on top is to avoid the oxidation that would be produced by a layer of hot air striking the stock or bath. The air and gas should meet about 2 feet above the metal, according to some authorities 5 feet, but this will bring it too near the roof in the ordinary furnace. If they meet much less than 2 feet above the metal, combustion can hardly begin freely before it is checked by striking the stock or bath; if much more, the most intense temperature above the bath causes the roof and sides to suffer.

The pitch that the ports are given is an important matter: if too flat, the flame is not brought down sufficiently on the metal, and combustion is too high up in the melting chamber. The tendency in such a case is for the brickwork to receive the maximum temperature rather than the metal; if too steep, the flame is brought down upon the stock before combustion is completed when the full heat value of the gas is not developed; besides, there is a tendency for the heat not to be properly distributed over the hearth.

11. Wellman Rolling Furnace.—Fig. 4 shows two Wellman rolling, or tilting, furnaces—one in the normal or melting position, the other in the position to pour steel. The furnace consists of a strongly framed steel casing approximately rectangular in section, inside of which the brick lining is built up. On the under side are fixed two curved rockers that roll and are supported by strong steel bracings; when tilted to pour off, the furnace moves forwards on these rockers. The movement is accomplished by two hydraulic cylinders *c*, placed underneath and the upper ends of their piston rods attached to the pouring side. To tilt the furnace, water is admitted to the top of the cylinder when the piston is pulled down. In case of accident or failure of the water pressure, the furnace returns by its own weight to the level position.

The sides and ends of the furnace consist of steel structural work tied together and stiffened with plates, angles, and framed steel structure *d* and are separate from the body of the furnace, being carried on four flanged wheels. The uptakes from the regenerators are carried to about the level of the furnace bottom, and across the top of each is laid a short track on which the wheels of the port structure rest. Two cast-iron water troughs *e* extend around the upper part of the uptakes, and on the under side of the port openings are rings that project into the water troughs, thus forming a water-sealed joint between the movable port and fixed uptake, preventing the leakage of gas and air in passing in or out of the furnace. As mentioned above, the joint between the fur-

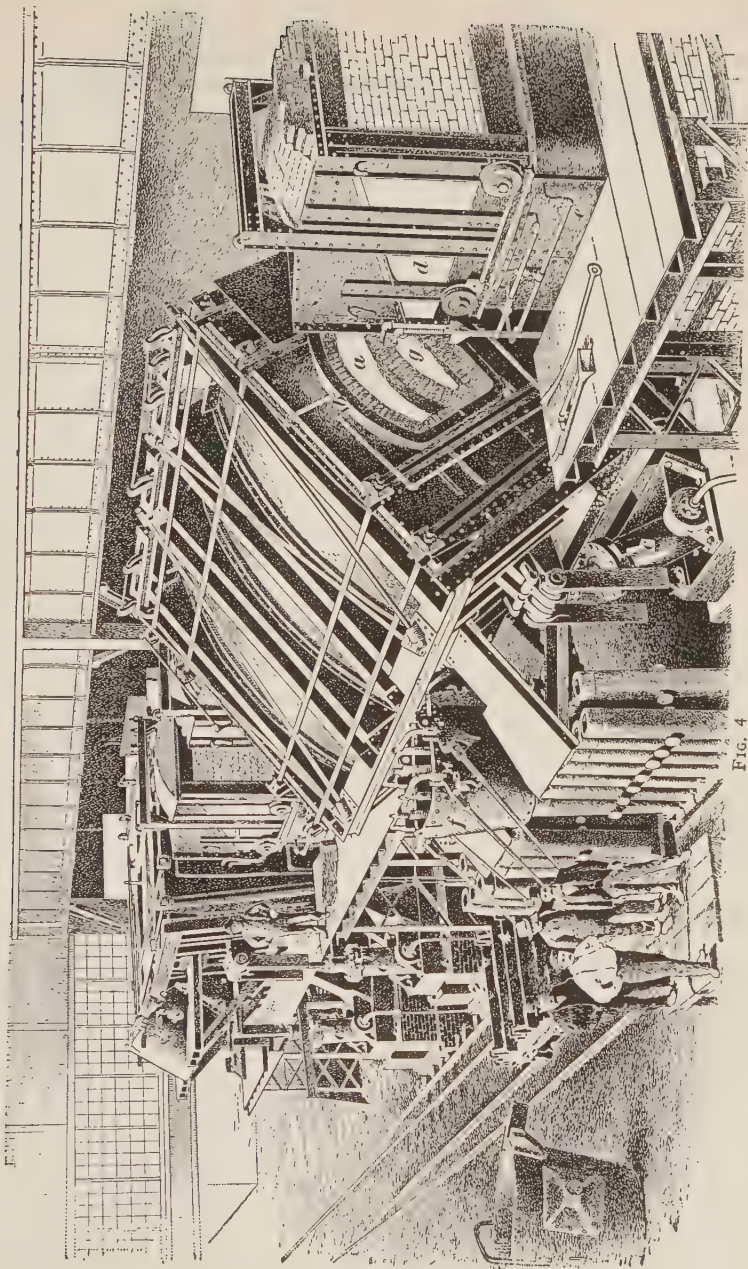


FIG. 4

nace body and ports is made by water-cooled rings in each, so that both the vertical and horizontal joints of the ports allow practically no leakage.

When about to pour, each port is drawn back to avoid the friction between them and the furnace ends. The channels across the top of the port structures act as bails by which they can be picked up from their track by an overhead crane, set aside, and a fresh pair placed in position.

The regenerative chambers are arranged in the same general way as in the ordinary furnace, but are always placed back of the furnace under the charging platform. The valves for reversing and controlling the gas and air are similar to those of the fixed furnace. The lining in acid furnaces is silica brick, both on the sides and on the roof; in basic rolling furnaces, the magnesite bricks are carried in the back wall so as to be above the slag when the furnace is being poured, as the basic slag would flux with any silica brick. The tapping hole is so arranged as to be always above the level of the bath when melting; it is fitted with a heavy flanged-steel casting riveted to the furnace body; holes in the outer flange serve to readily attach either the forehearth or pouring spout, if a ladle is used for casting.

12. Forehearth.—This part of the furnace may be described as a special ladle attached to the front of the tapping hole, and is a special feature of the Wellman rolling furnace, and was developed by S. T. Wellman. It allows the steel to be poured directly into the molds without the use of a ladle. It is a box-shaped casting shown at *f*, with a flanged opening on one side corresponding to the tapping hole to which it is bolted. It is brick-lined and is provided with two pouring holes and stoppers. When the furnace is tilted, the metal flows into the forehearth and is thence tapped into the ingot molds on cars which are pushed along under the forehearth to be filled. Each car, or bogie, usually carries two molds which are placed the same distance apart as the pouring holes, so that two molds can be filled at once, thus facilitating the casting operation. The forehearth, while per-

forming the function of the casting ladle to a certain extent, differs from it in that it does not become a reservoir for any considerable amount of metal, but acts more as a passage for the metal from the furnace to the ladle. A pouring spout may be readily substituted for it and the steel run into the ladle as in the ordinary practice.

13. Advantages of the Rolling Furnace.—Rolling furnaces have come into extended use in the past few years, and their future seems to be assured. Some of the reasons for this are the following:

No trouble results, nor is time lost in taking care of the tapping hole, as this is always above the level of the bath, and must be stopped simply to exclude air.

It permits the ready removal of slag. This becomes of greater consequence as impure irons, producing large amounts of slag in the basic process, are used.

The partly reduced metal is easily transferred from one furnace to another, and the slag is gotten rid of at the same time.

In pouring, as the joints with the ports are broken, the gas must be shut off; this at first seems a disadvantage, but is the reverse, as the cold air admitted at the ends chills the surface of the slag without affecting appreciably the temperature of the metal, and prevents boiling and violent action while pouring.

Holes form in the bottoms of all furnaces even with the most careful attention. In this event fixed furnaces must be bailed out with rabbles, and this can frequently be only partly done, so that metal is left to be absorbed by the bottom, which becomes more or less soaked with it and oxide of iron, thus very greatly reducing its power to withstand the action of slag and metal. In the tilting furnace, all the metal and slag can be removed after each heat, leaving the bottom dry; a considerable saving of metal results from this, as well as better preservation of the bottom.

It offers special advantages for the Talbot and Bertrand-Thiel processes described later.

14. Capacity of Open-Hearth Furnaces.—The early furnaces had a capacity of 3 to 5 tons, but they were gradually increased with the development of the process, construction, and means for handling readily the large amounts of stock and product. So far as the successful working of the furnace is concerned, there is practically no limit to the size of the furnace, but in taking care of the product obstacles are met. The largest furnaces yet constructed, in which the entire melt is withdrawn at once, take a charge of 220,000 pounds and yield about 100 gross tons of ingots. These furnaces have a melting chamber about 50 feet long and 16 feet wide. This will probably remain the standard size for large furnaces for some time. There are a number of reasons for this, not metallurgical and engineering alone, but economical as well. The prompt handling of a mass of 150 tons of molten steel within the allowable time and under the conditions of pouring is an engineering feat of such magnitude that it has been accomplished only within the last few years.

Present conditions demand that all the heat possible be saved, and for this reason steel from the furnaces must be put through the rolling mills as soon as possible, in order to take the least amount of reheating. With much larger heats than the above coming at one time, some of it will take a large amount of reheating before it can be put through the mills.

Another objection is the time required for pouring or casting (sometimes called *teeming*). Molten steel is really a delicate fluid and the limits of temperature within which it can be handled to produce good steel, or to avoid spoiling good steel, are not very wide. It is here that the skill and training of the steel maker counts, in particular that of the melter. If the heat is so large that it cannot be poured rapidly, it must either be too hot at the beginning to make a good steel, in order to get all of it out of the ladle and avoid a *skull* or *chilled heat*, or of the proper temperature at the beginning, with the result that it will be too cold at the end.

15. Gas and Air Valves.—Many forms of gas and air valves have been patented, but the ideal valve has not yet

been invented, as all give more or less trouble in furnace operations. Among these troubles are the cracking or warping of the seat or the box due to the uneven temperature to which they are subjected. A deposit of soot and tar in the gas valve requires cleaning, or leaks ensue from failure of the valve to close tightly.

16. Siemens Valve.—The Siemens, or butterfly, valve is the oldest form of reversing valve and still largely used. It is the simplest and, in many respects, the best type devised. Fig. 5 shows this valve in section. It consists of the outer

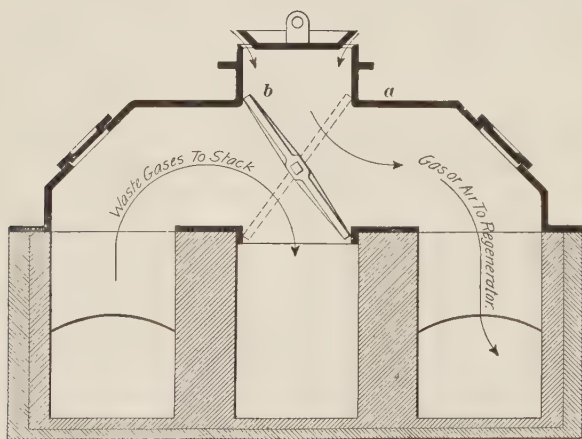


FIG. 5

casing, or box *a*, described above, and the elliptical tongue or butterfly, *b*, which is the valve. The objections to this type of valve are: (1) The warping and cracking of the cast-iron tongue and box so that gas leaks through to the stack, as the pull to the latter is stronger than the pressure of the gas to the furnace. (2) It is exposed to the hot producer gas on one side and the waste gases on the other, so that cracking and warping frequently occur, causing delays in changing and increasing the cost of repairs. (3) A deposit of soot and tar around the joints prevents the valve from closing tightly and allows gas to leak.

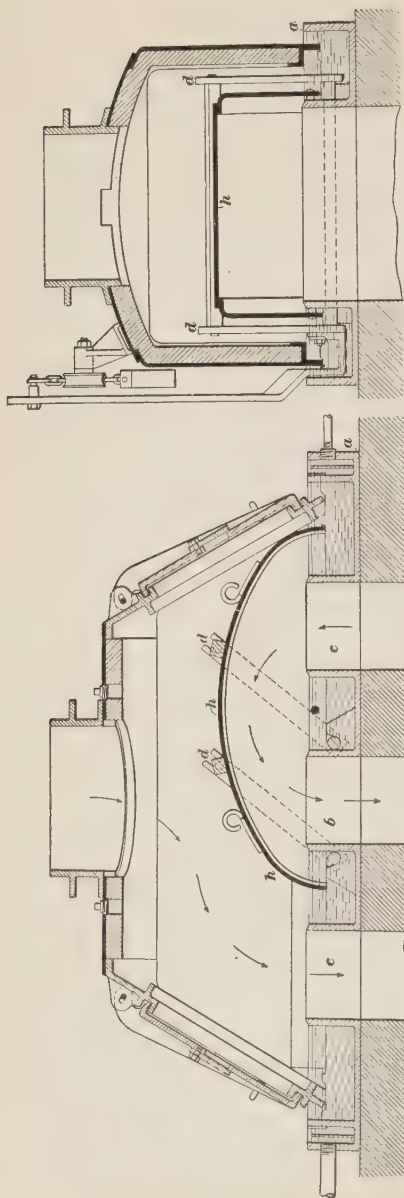


FIG. 6

While the waste gases pass to the stack for the most part at 600° to 800° F., they occasionally escape at red heat; then the valve suffers. Water cooling of both valve and box has been tried, but with little success. The advantages of the Siemens valve are simplicity and cheapness, so that even if they require frequent repairs, they can be made quickly and at a comparatively small cost.

17. Forter Valve.

The troubles with the Siemens valve have led to an almost endless number of valves which are designed to avoid its defects. Water cooling of the parts in contact with the hot gases is the essential feature of most, and a water seal of many. The Forter valve is perhaps the most perfect of this type, the general arrangement of which is shown in Fig. 6. The base plate, or trough casting *a*, is

made of cast iron and holds about $2\frac{1}{2}$ inches of water. It has three openings having flanges the height of the outside flange, corresponding with those in the brickwork to connect with the stack flue *b* in the middle and the regenerator flues *c* to the furnace on either end. Two of the openings are covered by a movable plate-steel or cast-iron hood *h*, connecting one or the other of the regenerator flues with the stack flue. This hood performs the office and corresponds to the *butterfly* in the Siemens valve. It is carried on arms *d* that lift it out of the water seal in reversing, describing an arc of a circle, moving so as to connect the opposite regenerator flue and stack flue and is dropped into the water seal in its changed position. This movement is accomplished by an outside lever connected to a shaft controlling the inside lifting arms; this shaft and the bottom edges of the hood are under water when seated, thus making a gas- or air-tight water seal. Running water is supplied to the base plate at one end to keep the seal cold and replenish the loss by evaporation, the overflow being carried off at the other end.

18. Dampers.—The flow of the waste gases to the stack is controlled by a damper in the stack flue, usually at the base of the stack. Dampers should also be placed in each flue leading from the reversing valves to the regenerators, in order to effect an even distribution of heat to the chambers, or to work one chamber hotter than the other.

ACID AND BASIC OPEN-HEARTH SYSTEMS

19. General Remarks.—The open-hearth process divides itself into the acid and basic systems. In the former the hearth is made of acid material—silica in the form of silica sand or silica brick; in the latter, the hearth and such portions of the side walls as are likely to come in contact with the slag, are made of basic material—magnesite or dolomite. The hearth is inert, taking no part in the reactions of the process, but in order that it is not fluxed, it must be made of a material to correspond to the character of the slag produced.

The slag is the solvent which absorbs the oxidized substances. The acid is the original open-hearth method and was practically the only one worked on any important scale until 1890; the basic is now the more important process and is becoming of even greater importance each year. The construction of the furnace, with the exception of the hearth, as noted above, is identical for either acid or basic work, the melting chamber, ports, and regenerators being the same; hence, a furnace can be changed from one to the other by substituting the one or the other lining.

20. Acid and Basic Linings.—The term acid and basic refer to the character of the lining, or more exactly to the slag carried in the melting operation. Hearths of neutral material—bauxite or chromite—have been unsuccessfully tried, the idea being that either a basic or acid slag could then be worked.

What was said in the Section on the *Manufacture of Iron*, in reference to fluxing of linings should be employed here, namely: a slag will dissolve any compound which reduces its melting point. Thus, a slag even slightly more basic than the most fusible possible combination, will *cut* an acid lining, and a slag not quite as basic as the most fusible combination, will corrode a basic lining. Neutral materials are substances which do not increase the fusibility of any of the usual slags. The trouble with them is that their melting point is too low, or their cost is too high. A neutral layer—say chromite—on the floor of the ports, where it will catch the splatterings of the slag during boiling, or a layer placed between the basic bottom and the acid furnace walls, will often protect the furnace. The terms *acid* and *basic* applied to open-hearth slags are not absolutely strict, but relative, as an acid slag is frequently basic enough to react with a sand bottom, while a basic slag is often acid enough to react with a magnesite bottom.

21. Wellman Charging Machine.—Formerly all the stock was charged in the furnace by hand. The pig and heavy pieces of scrap were placed on a peel and guided to the part of the hearth desired; small and light pieces were thrown

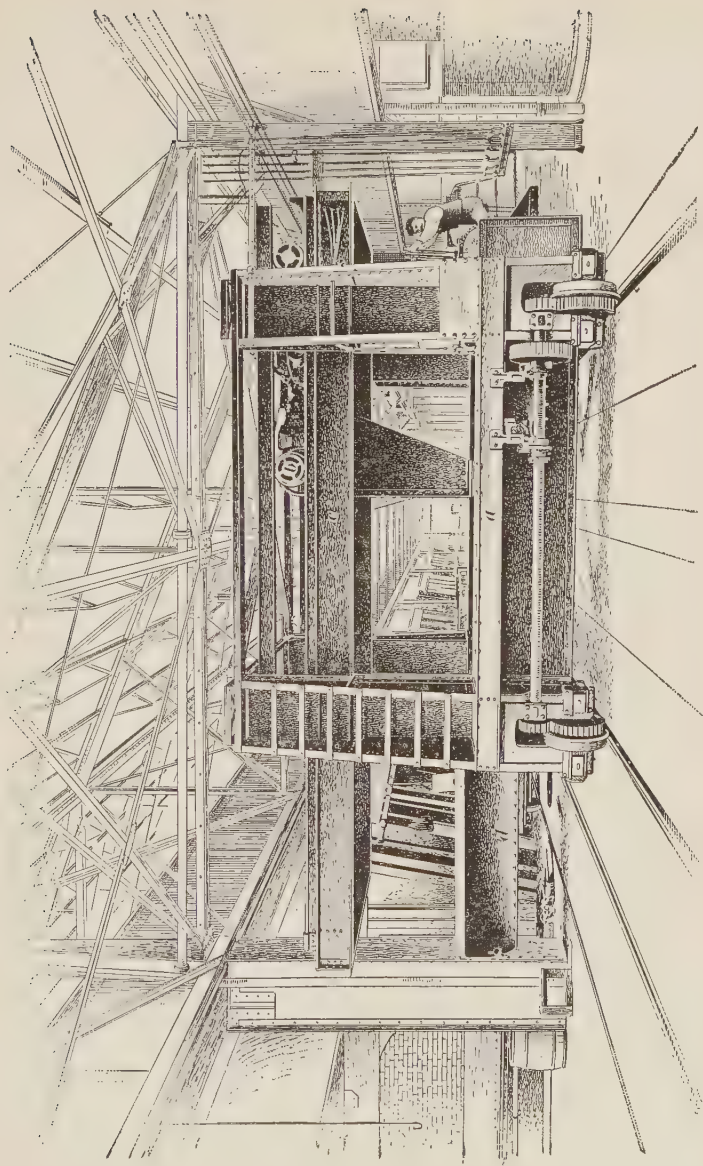


FIG. 7

directly in by hand, shovel, etc. This has been superseded in large plants by the Wellman charging machine, shown in Fig. 7. The first machines were operated by hydraulic or steam power, but are now operated entirely by electricity. The machine consists of a steel frame *a* carried on four wheels on tracks on the charging floor. A movable carriage *b* is suspended on beams *c* at the top of the machine, the beams projecting beyond the main body of the machine, and over the track next to the furnaces on which stand the cars with the charging boxes *d*. To the front of the carriage are hung supports to which is attached the peel, or ram (not shown in the figure), with a rectangular head for inserting into the casting on the end of the charging box containing the pig iron, scrap, etc. Electric motors are provided for the different motions on the track in front of the furnaces, such as moving the carriage back and forth to introduce the charge, and revolving the peel on its axis to drop the stock from the box into the furnace. The operator is carried on the movable carriage so that he has a close view of the movements of the machine and can readily control them by suitable levers conveniently placed. In operation the machine picks up the box filled with stock, is moved in front of one of the furnace doors, which is raised, the carriage advanced, the box inserted in the furnace, and the ram revolved, dumping the stock. After dumping, the operations are reversed and the box replaced on the narrow-gauge car.

22. The charging boxes are special, rectangular, steel-plate boxes with both sides slightly flaring so that the stock will readily drop out when overturned. The ends are of cast iron or steel, the end next the machine being always of cast steel, as it carries the weight of the box. The boxes hold from a few hundred pounds of light bulky scrap to 4,000 pounds of pig iron, or heavy scrap. The charging machine has done more to reduce the cost of making steel by the open-hearth process than any single invention or appliance; at the same time it has taken the hardest and hottest part of the furnace work from the men. In a large plant, one machine charges

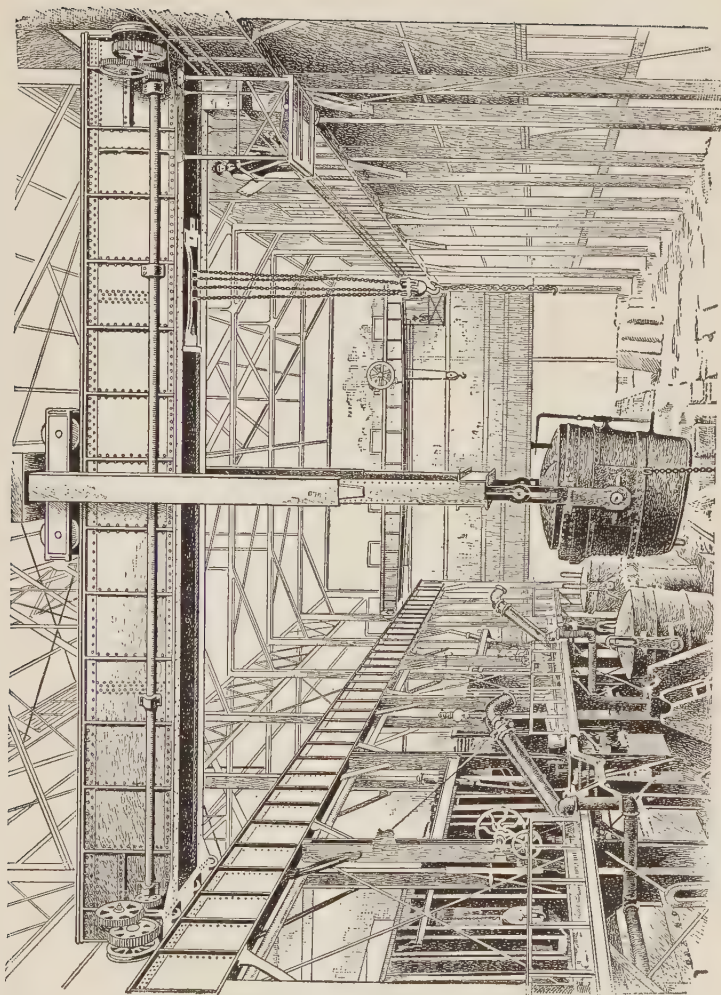


FIG. 8

five or six furnaces, displacing three or four men per furnace. It is economical even in small plants of one or two furnaces.

23. Cranes.—The electric traveling crane is the standard appliance for handling the metal and slag after tapping and for doing the pit work, such as placing the molds for the steel, handling ingots, getting up stock, etc. The hydraulic swing crane was formerly used and has some advantages such as simplicity and cheapness to install and operate and small likelihood of getting out of order, with the consequent delays and accidents.

24. Ladle.—The steel is tapped from the furnace into a ladle made of heavy, riveted plate steel, lined with from 4 to 6 inches of firebrick, usually two courses, the one next to the steel shell being of a low-grade firebrick laid flat, $2\frac{1}{4}$ inches thick, the inner one of a good-grade firebrick, either laid flat or on edge, $4\frac{1}{2}$ inches thick. Sometimes only the one course is used, but this is not a safe practice for heats of 30 to 60 tons. The steel is always poured from the bottom of the ladle, so as to keep the slag out of the metal and at the same time give better control over the casting operation. In the bottom of the ladle near its circumference is placed the nozzle of graphite or hard-burned firebrick. This has a cup-shaped top tapering to a hole from 1 to 2 inches in diameter. The stream of metal is controlled by a stopper rod, which is protected by jointed fire-brick sleeves and carries on its lower end a graphite plug called the *stopper head*. When pouring, the upper end of the rod is connected to a slide, on the upper outside edge of the ladle, provided with a suitable lever for opening up and shutting off the stream of metal. Fig. 8 shows the casting side of an open-hearth plant with a 60-ton traveling ladle crane and a 40-ton ladle in position for pouring the heat.

Fig. 9 shows a section through an open-hearth plant. In the figure, *a* is the charging machine of the low type; *b*, the open-hearth furnace; *i*, the producer-gas main; *j*, a gas valve; *h*, the regenerator chamber; and *k*, the stack. The traveling crane *l* over the charging floor is for handling stock, etc. At

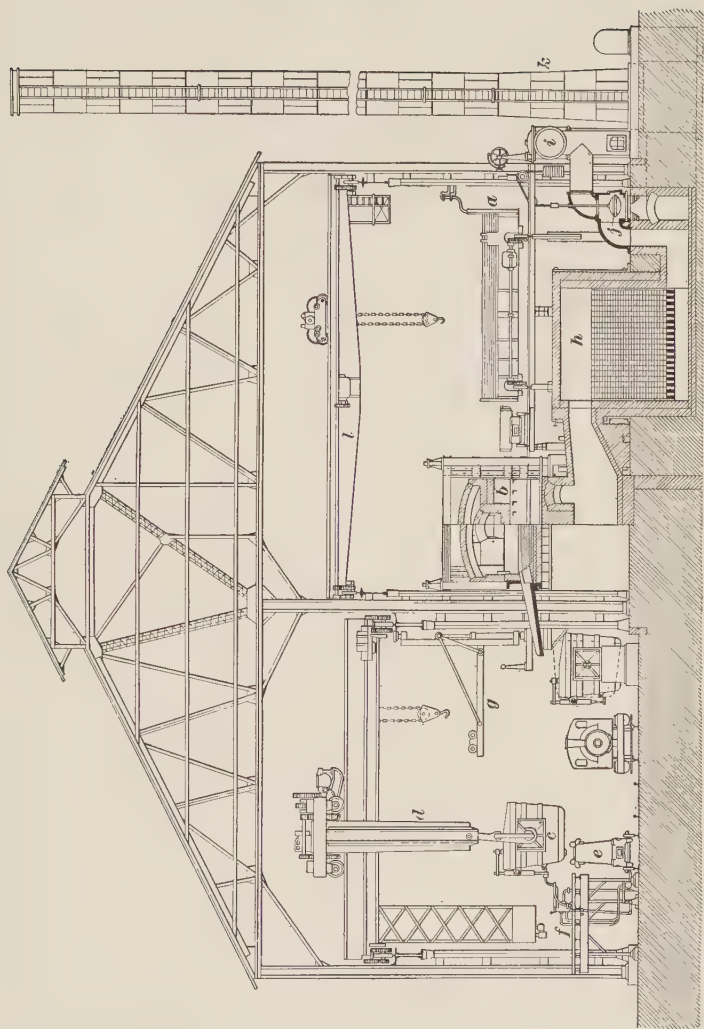


FIG. 9

the left is shown the casting house, in which *a* is the ladle crane; *c*, the ladle; *e*, the molds on the car; and *f*, the pouring platform. The small hydraulic crane *g* is used for handling the spout, setting stopper, etc.

GASEOUS FUEL USED IN OPEN-HEARTH FURNACES

25. Introductory.—A regenerative furnace for either melting or reheating can be operated with natural gas, artificial, or producer, gas, or petroleum, or pulverized coal.

NATURAL GAS

26. This is the ideal fuel, and the one generally used where available, but it is of much less general importance than producer gas because of its comparatively limited geographical distribution and the probable uncertainty as to its permanency. It was first used in the manufacture of steel in Pittsburgh in 1879, and is used principally in Western Pennsylvania and adjacent parts of Ohio and West Virginia. No one theory as to its origin is generally accepted, although a number have been advanced. It is commonly associated with oil, and is probably produced from it by distillation under certain conditions of temperature and pressure within the earth, or by distillation from coal, or the two combined. The depth of the wells varies from 1,000 to 3,000 or 4,000 feet. The pressure at the wells frequently amounts to several hundred pounds per square inch, rendering it uncontrollable. In the lines, as furnished for use, a pressure of from 6 to 10 ounces per square inch is maintained.

The chief advantages in its use are: (1) Higher calorific value, with consequent increase of output; (2) greater purity, with respect to sulphur, thus producing purer steel or allowing the use of poorer stock; (3) convenience and cleanliness in use.

27. Composition of Natural Gas.—Natural gas is essentially marsh gas, or methane, CH_4 , with varying admixtures of other members of this series of hydrocarbon gases, together with hydrogen. It usually contains from 60 to 70 per cent. of methane and 20 to 30 per cent. of hydrogen.

TABLE I

Constituent	Sample			
	No. 1 Per Cent.	No. 2 Per Cent.	No. 3 Per Cent.	No. 4 Per Cent.
Carbon dioxide, CO_2 ...	.80	.60		
Carbon monoxide, CO .	1.00	.80	.58	1.00
Oxygen, O	1.10	.80	.78	2.10
Ethylene, C_2H_4	.70	.98	.98	.80
Ethane, C_2H_6	3.60	5.50	7.92	5.20
Methane, CH_4	72.18	65.26	60.70	57.85
Hydrogen, H	20.62	26.12	29.03	9.64
Nitrogen, N				23.41

Table I shows the analyses of four samples, giving an idea of its composition.

The high percentage of nitrogen in No. 4 is probably due to air, as natural gas seldom shows any considerable percentage of it. The average heating value of Pennsylvania and Ohio natural gas is 1,007 B. t. u. (British thermal units) per cubic foot.

28. Introduction of Natural Gas Into the Furnace. Natural gas is not regenerated (preheated), but is introduced directly from the supply main into the ports of the furnace. Regeneration was tried when the gas was first used, but the heat of the chambers decomposed the rich hydrocarbons and caused a deposition of carbon in the chambers in the form of a hard, glassy coke; it also reduced the gas to hydrogen or lower hydrocarbons, having less heating value than the original gas, besides losing the value of the deposited carbon,

which would be burned on a reversal of the furnace, the products of this combustion escaping directly to the stack instead of being utilized in the furnace or chambers.

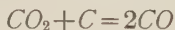
ARTIFICIAL GAS

29. Under the name artificial gas, many forms and kinds of gas have been made and used at various times, but the only one that need be given any extended consideration in connection with the manufacture of steel is producer gas. Other artificial gases which are made by various processes are coal gas, water gas, and oil gas, or a gas produced by a combination of any or all these processes. It is technically possible to use all these in making steel, but it is not commercially possible at this time, owing to the higher cost of producing a given calorific effect.

30. Producer Gas.—The apparatus in which producer gas is made, is a cylindrical riveted shell of boiler steel, lined with firebrick. The early producers were made rectangular in section, but the circular section was adopted as offering many advantages, and is now wholly used. As before stated, the success of the open-hearth furnace, or of the regenerative furnace to whatever purpose applied, depends on the use of a gaseous fuel. The producer may, therefore, be properly considered a part of the furnace and its development has been simultaneous. Producer gas may be regarded as the general fuel of regenerative furnaces; natural gas, while superior in every way, can be considered only as a special fuel.

31. Siemens Producer.—Fig. 10 shows the original Siemens producer. It is a rectangular firebrick chamber having one side *b* inclined at an angle of 45° to 60° , provided with a grate *c* at the bottom. The coal is fed into the opening *a* at the top, making a thick bed as it falls to the grate, through which air is admitted to the ignited fuel, and converts a part of the carbon to carbon dioxide, CO_2 , which, in passing up through the incandescent mass, is reduced to

carbon monoxide, CO , by taking up an additional atom of carbon.



This carbon monoxide is diluted by the inert nitrogen of the air and by some of the carbon dioxide escaping reduction, and is mixed with the hydrocarbon gases and vapors distilled from the coal. The gas passes through the flue h to the main gas flue i . The gas is enriched by the decomposition

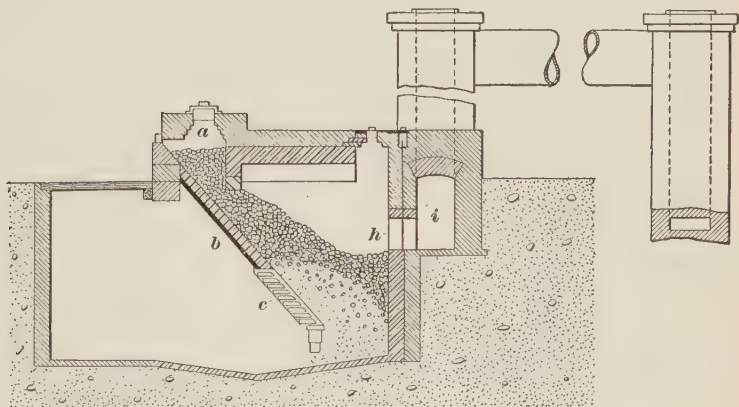
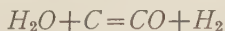


FIG. 10

of the moisture, which is always present in the air, or of the steam used for injecting the air. This forms two combustible gases, carbon monoxide and hydrogen:



Originally air was drawn into the producer through the grate by natural draft, later by steam being blown in with it. It was soon discovered that a more economical way was to introduce the air and steam by means of a steam jet, so arranged that the discharge of the steam draws air into the producer. Only a limited amount of steam can be used continuously, as the reaction $H_2O + C = CO + H_2$, is so strongly endothermic (absorbing heat), that the temperature in the producer is lowered below the working point.

32. Water-Seal Producers.—The principal improvements in producers since the original Siemens producer was made have been the adoption of a closed bottom, and mechanical stirring of the bed of coal. To accomplish this, the producer proper rests in a water pan through which the ashes

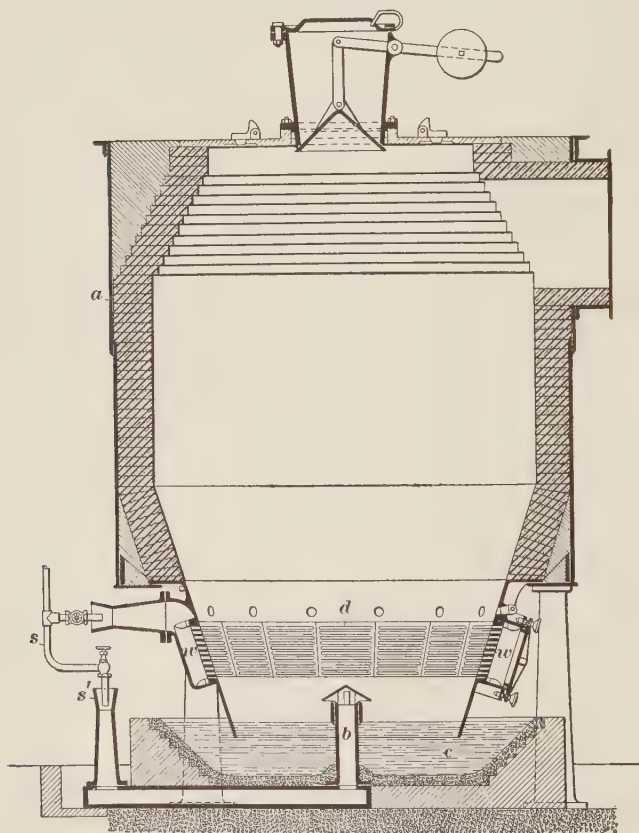


FIG. 11

or clinkers are raked out. This water acts as a seal, preventing the escape of gas and the introduction of air, which occurred in the old producers while the fires were being cleaned, contributing much to their irregular working and the poor quality of gas. Instead of being flat, the grate is conical,

underneath which the pipe conveying the air and steam terminates, introducing these in the center of the producer. This insured a more even and regular circulation within the chamber than when they are drawn in at the side. The air naturally seeks the passage of least resistance and a serious defect of older producers, where the air and steam came in at the side, was the tendency to creep up the walls of the producer without the CO_2 first formed being reduced or the steam decomposed. This also produced excessive heat, causing the ash to clinker and scaffolds to form on the side walls. The same conditions may exist to some extent in any producer improperly managed, but they are much less liable to occur if reasonable care is used.

Mechanical stirring keeps the bed free from vertical channels through which the CO_2 and steam may pass without being decomposed into carbon monoxide and hydrogen.

33. Forter Water-Seal Producer.—Fig. 11 shows one of the most successful and a general type of the water-seal producer. It is the usual brick-lined shell of steel *a*. There are usually but two steam jets *s* on opposite sides to introduce the air and steam into the wind box *w* and under the grate. In this one a third steam jet *s'* forces them into the center of the producer by means of a pipe beneath the ash-pan, with the vertical part of it terminating below the grate, as shown at *b*, and protected from ashes by a cone-shaped hood. The wind box has a number of air-tight doors through which sections of the grate can be removed to bar out any large clinkers accumulating on the bottom. The ashes slide down into water in the ash-pan *c* as the coal is burned, and are removed from time to time without interfering with the working of the producer.

34. Fraser-Talbot Mechanical Producer.—Recently a producer has been patented, called after its inventors, the Fraser-Talbot mechanical gas producer, in which the poking or stirring is done by mechanical means. This producer, shown in Fig. 12, is essentially the same as the ordinary water-seal type. A hollow shaft *a* passes vertically through the

producer, and to this radial arms *b* are attached. This shaft has both a rotary and a vertical motion; the former revolves the arms through the mass of coal, and the latter constantly

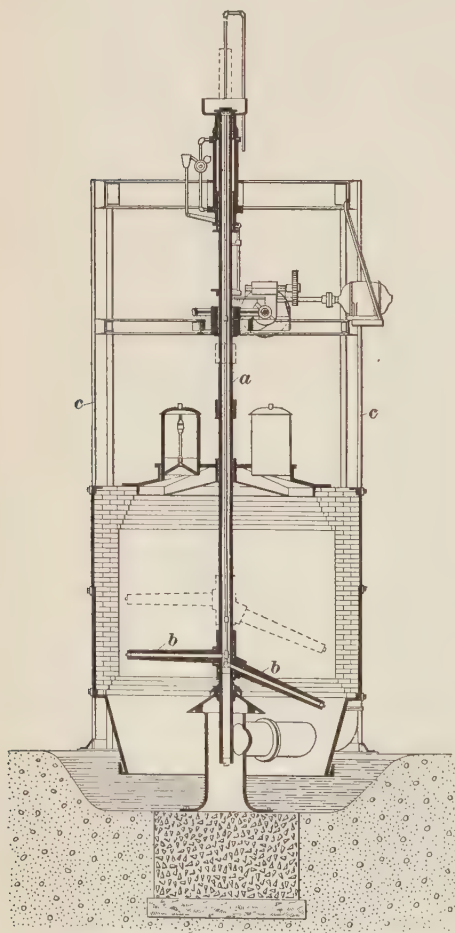


FIG. 12

changes the plane of rotation so that the horizontal arms are made to keep the whole mass thoroughly broken up for the passage of air. The shell of the producer is riveted to I-beam columns *c*, which extend above the shell and form a framework to which is attached the rotating and lifting mechanism, which is driven by an electric motor. The central shaft and radial arms are water cooled, as they are likely to reach a low-red heat and bend from the resistance of the bed of fuel. The advantages are in the quality and quantity of gas made per unit and the lower cost of labor. The fire is kept much more uniform than by the best hand poking, so that the carbon dioxide formed is more certain to be brought in contact with the carbon and reduced to carbon monoxide. Holes in which the CO_2 can escape reduction cannot form in the fuel bed from insufficient poking.

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35. Fuel Employed for Making Producer Gas.—The fuel to make producer gas is bituminous or anthracite coal, coke, charcoal, peat, or even wood. We will consider only the first, as the others are of so little importance that they can be ignored, being used to a small extent only in steel works and under special or isolated circumstances. The coal used should be a good quality of gas coal, low in sulphur, having a low or moderate percentage of ash, and of such a character as not to clinker on the grate. While practically all bituminous coals (if not too high in sulphur) may be used, there is a decided difference in their value. Proximate and ultimate analyses of four samples of good average coal for producer

TABLE II
PROXIMATE ANALYSIS OF COAL

Number of Sample	Volatile Matter Per Cent.	Fixed Carbon Per Cent.	Ash Per Cent.	Sulphur Per Cent.
1.....	36.20	58.20	5.60	.85
2.....	34.70	58.45	6.85	1.00
3.....	32.80	58.10	9.10	.92
4.....	33.75	55.00	11.25	1.02

ULTIMATE ANALYSIS OF COAL

Number of Sample	Total Carbon Per Cent.	Hydrogen Per Cent.	Oxygen and Nitrogen Per Cent.	Ash Per Cent.	Sulphur Per Cent.
1.....	75.63	4.30	13.62	5.60	.85
2.....	76.63	4.57	10.95	6.85	1.00
3.....	73.92	4.73	11.53	9.10	.92
4.....	72.87	4.76	10.10	11.25	1.02

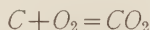
gas are given in Table II. The former (with the sulphur) is all that is necessary for the ordinary valuation of a coal for this purpose.

Ordinarily, the more volatile matter there is in coal the richer is the gas produced, as it contains more hydrocarbons. The volatile constituents in the coal give the gas illuminating power on combustion, and thus make it radiate heat better in the furnace laboratory. The radiant energy is believed to come from the reflection of myriad particles of separated carbon heated to incandescence. Thus, hydrocarbons which deposit carbon during combustion contribute illuminating power to the gas.

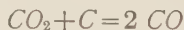
Sulphur should not exceed 1 per cent., but this depends on its condition in the coal—if it is in such a combination that it is mostly oxidized, remaining with the ash as sulphate, it may be much higher; if principally volatilized, even this amount may cause the steel to absorb too much of it from the gas.

36. Producer Reactions.—The reactions taking place in making producer gas are:

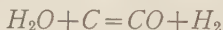
1. Carbon burned to carbon dioxide,



2. Reduction of the CO_2 by the hot coal to carbon monoxide,



3. Incandescent carbon decomposing water vapor,



On the grate in the bottom of the producer are the ashes which serve to heat the steam and air; and, in connection with the water seal, prevent the escape of gas in cleaning the fires. Next above this is the bed of incandescent fuel, where the air and steam combine with the carbon in the above reactions. On top of this is the section where distillation occurs. The temperature is constantly lowered by the addition of fresh coal, but the heat of the bed beneath keeps up the distillation of the volatile products of the fuel. While the ash bed is sharply separated from the one above, the two upper ones overlap and their reactions occur to a considerable extent in the same region.

The incandescent bed should be deep enough and sufficiently well stirred to insure the decomposition of most of the carbon dioxide. Above it should be a layer that is at a black heat.

The reactions are not all as simple as expressed in the above equations, as a series of more or less complicated processes of dissociation and synthesis occur. Under certain conditions, part of the distillation may take place lower down in the hotter section, when the original hydrocarbons will be partly broken up and the new ones formed. According to Siemens, the surface regenerators are hot enough to cause some of the carbon deposited in them to be taken up by the carbon dioxide and water vapor. This absorbs heat, which is given back on combustion in the furnace, so that the calorific power of the gas is increased. The production of gas is regulated nearly automatically, as the amount of gas withdrawn determines the supply of air to the grate—assuming, of course, that the producer is otherwise properly managed. One volume of carbon monoxide produced requires $2\frac{1}{2}$ volumes of air containing 2 volumes of nitrogen to pass through the grate, 1 volume of water vapor on decomposition gives 1 volume of hydrogen and 1 volume of carbon monoxide.

37. Operation of the Producer.—From the preceding description, the operation of the producer will be readily understood. The fuel is fed in through a bell and hopper, by shoveling or chutes from overhead storage bins. As the coal becomes hot, it partially disintegrates and cakes, forming layers, through which the air is forced with difficulty, or channels are made through the coal so that a large part of the carbon dioxide first formed will not be brought in contact with carbon and reduced to carbon monoxide. To avoid this, *poker holes* are placed in the top of the producer, through which the incandescent mass is at intervals of a few minutes broken and stirred with long pokers. Ashes and clinkers are removed about every other day, depending on the quality of the fuel and the rate at which the producer is driven. Other conditions being right, the hotter and deeper the fire, the

better the reactions take place. The usual depth of fire is about 6 feet, varying with the ashes on the grate and the rate of feeding the fuel. If the contents of the fire gets much deeper than this, it is impossible to keep the bottom of it broken up, however well it is poked; if much shallower, the carbon dioxide and water vapor are not decomposed.

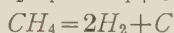
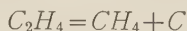
38. Composition of Producer Gas.—Under the conditions outlined above, the limits of composition of producer gas will usually be about as given in Table III.

TABLE III

Constituents	Minimum Per Cent.	Maximum Per Cent.	Good Average Per Cent.
Carbon dioxide.....	.5	8.0	3.5
Oxygen.....	.0	.5	.0
Ethylene.....	.0	.5	.0
Carbon monoxide	18.0	25.0	23.0
Hydrogen.....	6.0	12.0	8.0
Methane.....	1.0	4.0	3.0
Nitrogen.....	58.0	65.0	60.5

The first two columns are not to be understood as showing analyses of individual samples, but as the usual extremes of the component gases. Such extreme samples might rarely be obtained except in the nitrogen, but even this is exceptional, as the percentage of nitrogen remains quite constant at 60 to 62 per cent., the variation occurring mainly with the other gases. Steam is always present in the gas since some of that introduced with the blast, escapes decomposition. Another source is the combined water of the coal. The amount from the first source depends on the condition of the fire. Tar is always present in the gas, varying with different coals. It furnishes considerable heat value, which is usually estimated at from 6 to 12 per cent. of the total calorific value of the gas, not all of which, however, becomes

available in the furnace, as part of the tar is precipitated in the gas main, valves, and flues. The hydrogen comes from the breaking up of the hydrocarbons and decomposition of the steam. More or less of the richer hydrocarbons are always decomposed in the gas tube, producing large quantities of soot, as follows:



This deposition would occur in the hot chambers if not in the tube; hence, it is an unavoidable loss, and in the case of very hot gas fires it becomes excessive. The soot and tar partly close the gas tube and valves, which must be cleaned by burning out and scraping at the end of each week, and frequently require a partial cleaning during the week.

39. Calorific Value of Producer Gas.—The gas leaves the producer at a temperature of about 550° C. ($1,022^{\circ}$ F.) and is cooled to 100° to 150° C. in the tube. To avoid this loss of heat, the gas producer has been attached directly to the furnace, the gas passing from the producer directly to the ports being hot enough to burn without regeneration. This seems logical, and is correct from a theoretical standpoint, but the practical difficulties in the way of its operation have rendered it ineffectual. From the composition of the gas given in Table III, the calorific power may be calculated, but this is of no practical value to the steel metallurgist in the comparison of different gases, as conditions can seldom be sufficiently uniform in practice. For practical purposes a ton of bituminous coal is taken as yielding 140,000 cubic feet of gas; this amount, of course, varies with the coal, the type of producer, and its working. Ordinary producer gas gives an average of 120 B. t. u. (British thermal units) per cubic foot, or 1,068 calories per cubic meter. The calculation of the calorific value from the composition does not show all the heating value in a gas from bituminous coal. Gas may be made from anthracite coal having the same composition, but the heating value will be much less, owing to the absence of solid hydrocarbons in the flame imparting lumi-

nosity to it. The question of luminosity of the flame has much to do, in high-temperature work, with the effect produced. Between a luminous and non-luminous flame in the furnace, although the actual flame temperature resulting from the combustion of the gas may be nearly the same, there is the difference of rapid melting and entire inability to reach a steel-melting temperature. This is why anthracite coal will not produce a gas for steel making. At low temperatures there is little difference between the heating value of luminous and non-luminous gas. The incandescent carbon or hydrocarbons cause a large amount of heat to be given out by radiation. The importance of heating by radiation in the open-hearth steel melting was not recognized for a long time, and the furnace roof was built low, to confine the flame to the stock. It is now made high, and the radiative power of the luminous flame is utilized to give a large amount of the heating effect.

40. Arrangement of Producers.—Formerly the producers for the entire plant were connected to one main gas flue, from which branches went to each furnace. These branches were controlled by valves, so that any one furnace could be cut out without interfering with the others. Objections to this arrangement are: (1) The furnaces nearest the producers and those on the end of the line seldom have the same gas pressure; (2) the deposit of soot and tar chokes up the tube nearest the producers, necessitating more frequent cleaning or a deficient supply; (3) it is more difficult to maintain a steady supply than if each furnace has its own producers.

The furnaces at a moderate distance from the producers receive the best gas; if too close, the gas is apt to be so hot that more of the hydrocarbons are decomposed in the regenerators, lessening the heating power and increasing the liability of the regenerators being choked with soot. On the other hand, if the gas must travel too far, it is cooled so much that carbon and tar deposit in the cooler part of the tube, producing practically the same effect as with too hot a gas.

To obviate these and other objections, some recent works have returned to an earlier plan of making each furnace independent by building separate producers. A more regular supply is assured in this way, a furnace not being affected by the varying demands of its neighbors. The claim is also made of some economy in labor and fuel, as the gas supply can be more closely adjusted to the demands of the melting house.

MANUFACTURE OF STEEL

Serial 2053B

(PART 2)

Edition 1

THE ACID OPEN-HEARTH PROCESS

1. General Remarks.—In the acid process only stock containing relatively small amounts of phosphorus and sulphur can be used, as with an acid slag these impurities are not eliminated. For this reason the field of the acid process is limited.

2. Hearth.—The acid- or silicious-lined furnace takes its name from the silica sand or brick used for making the bottom or hearth. In almost all cases a natural sand is used containing from 95 to 99.5 per cent. of silica, with .5 to 3 per cent. of alumina; the remainder consists of combined water, small amounts of lime, magnesia, and oxide of iron. All silica sands are not suitable for this purpose, a high degree of purity alone not being sufficient, much depending on the physical character of the sintered mass produced. Oxide of iron is the most objectionable impurity, as well as the commonest, in sands of the above percentage of silica.

In *making bottom*, the furnace is gradually heated to nearly a working temperature, when sand is thrown on the bottom to a depth of several inches. This is allowed to sinter when more sand is thrown on in thin layers, sufficient time being allowed between each addition for perfect setting. The sides and ends are gradually thickened until the hearth assumes a saucer-like shape. The hearth finally has a thickness of 16 to 24 inches on the bottom and sides; the latter are carried about a foot above what is to be the level of the

metal bath. Sometimes two sands of different fusing points are mixed together, the one so refractory that it will not soften at the full working temperature of the furnace, the other softening at a lower heat. By varying the percentages, a mixture may be obtained sintering or setting through a considerable range of temperature. The bottom becomes so hard that it is not eroded by the stock at the melting temperature and will resound if struck with a tool. Upon these qualities of strength and hardness the endurance of the lining largely depends.

3. Charge.—The charge will vary considerably at different plants or under varying conditions at the same plant. Commercial considerations, namely, the relative price of pig iron and steel scrap, are the controlling factors. It may be all pig iron in the pig-and-ore process, or pig iron as low as zero and 100 per cent. scrap. Under such conditions coke is charged with the stock, to furnish carbon and to prevent oxidation; this is exceptional practice and is not so sure of producing good steel; it is therefore resorted to only where scrap is much more abundant and cheaper than pig iron. In the pig-and-scrap acid process, the charge is approximately one-third pig metal and two-thirds scrap. In general, the charge is so adjusted that when melted the bath contains from .3 to .6 per cent. more carbon than the desired finishing point. If too little pig iron is used, the bath has all the carbon, silicon, and manganese oxidized before the metal is ready to tap, when it becomes pasty and oxide of iron is rapidly formed, thus wasting the metal. The ferrous oxide also scorifies the bottom. A further and more serious injury is the introduction of oxides into the bath that are difficult to remove and injure the steel, making it *wild* to handle in the furnace and ladle. Finally, if not enough carbon is included in the furnace charge, it usually is too soft when it reaches the molten condition. This purity makes its melting point high; therefore, it is pasty and seems to be cold.

The remedy for a heat melting low or soft is simply to add pig iron to the bath—*pig up*—to give sufficient carbon and silicon to bring the bath to a boil and get the necessary tem-

perature to tap the heat. On the other hand, if too much pig iron has been charged, no harm is done to the quality of the steel, as there is then a bath high in carbon and possibly containing some silicon and manganese. These delay operations, but they can be boiled out by the action of the flame alone, or almost universally by the addition of ore, which hastens the oxidation of the impurities. The objections to pigging up are: (1) time is lost, as the addition of fresh pig lowers the temperature, the operation being held back while recovering this heat; (2) more pig is required than if the requisite amount had been added with the initial charge.

In California, and other places where steel scrap is abundant and pig iron is costly, the whole charge is made up of steel scrap with 15 to 20 per cent. of carbon in the form of coke breeze, fine anthracite, etc. This requires special skill and experience, but replaces the carbon of the pig iron.

In steel works the pig iron is commonly designated as *hard* and the steel or wrought-iron scrap as *soft* stock—the terms indicating the relative amounts of carbon.

4. Method of Charging.—Generally in an acid furnace the pig iron is charged on the bottom and the scrap on top in order to have the carbonaceous material next to the hearth so as to lessen the amount of corrosive ferrous oxide that comes in contact with the lining. Sometimes the pig is allowed to heat up, or partly melt, before the scrap is added. In plants where hand charging is used, the stock is gradually added, and, in the judgment of many open-hearth managers, the wait between the pig and the scrap charges gives the men a rest without delaying the operation. With a charging machine, it is more common to add all the stock at once; that is, continuously until all is in. The usual time of hand charging a furnace of 25 to 50 tons is from 2 to 4 hours; this may be considered practically a thing of the past, especially with large furnaces. With a machine, if continuous, from $\frac{1}{2}$ to $1\frac{1}{2}$ hours is required. The advantages claimed for slow charging are: (1) the stock has time to heat up as added, and melting goes on faster; (2) the furnace is not chilled by charging the

whole amount of cold stock in a short interval, thereby cooling the waste gases and the regenerators so that the gas and air are not sufficiently preheated for rapid melting. Against this view, it is maintained that in slow charging the furnace doors are up so long that a large amount of heat is lost by the admission of cold air to the melting chamber, and melting is thereby delayed, the loss from oxidation is also increased and more gas is used. In a properly designed and working furnace, with ample regenerative capacity, there should be no serious delay from too rapid charging, there being a sufficient reserve of heat in the checkers to keep up the temperature.

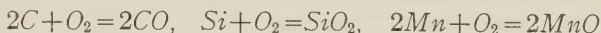
On an acid bottom the pig metal is charged first, a layer of it being distributed on the bottom and banks so that the scrap is kept from contact with the hearth. All of the scrap is then charged on top of the metal. If the scrap is charged on the bottom, the formation of ferrous silicate is excessive. This cutting, or scorification, may be a serious matter, as a hole may be started that will cut entirely through the sand bottom. The sand will also become impregnated with iron, so that its refractory power and ability to withstand the action of metal and slag is lessened.

5. Calculation of the Charge.—In a charge for an acid furnace, the composition of the pig is usually within the following limits:

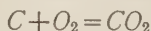
Silicon.....	1.25% to 2.00%
Total carbon.....	3.00% to 4.00%
Manganese.....	.40% to .80%
Phosphorus, not over.....	.10%
Sulphur, not over.....	.05%

The phosphorus and sulphur depend on the percentage allowed in the finished steel and the scrap used. Assuming the phosphorus and sulphur in the stock to be within the limits allowed in the steel, the calculation is based on the carbon, silicon, and manganese. These are all oxidized during the operation. Some of the oxidation is performed directly by oxygen in the furnace gases, but this is only when the boil-

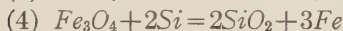
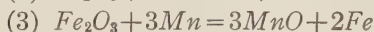
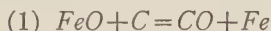
ing action throws the metal up and exposes it to the furnace atmosphere:



These reactions are all exothermic; that is, they all give out heat and increase the temperature of the furnace, just as the burning of coal gives out heat in our fires:



But the majority of the oxidation takes place through the medium of FeO in the slag and Fe_2O_3 or Fe_3O_4 added in the form of ore:



These reactions again all give out heat, and they also increase the yield by reducing iron from the slag or ore. The oxidation of carbon influences temperature in three different ways: First, by the exothermic reactions already cited; second, by stirring up the bath, because the gaseous CO , bubbling through the metal, produces an agitation which is sometimes very violent; and this naturally increases the contact between the metalloids and the oxidizing substances, and thus increases the action. Indeed, the bubbling throws metal up into the furnace atmosphere, where even CO_2 will do some oxidizing: $C + CO_2 = 2CO$.

Finally, the stirring of the bath often brings unpurified metal up from the bottom, where it has been lying unacted upon. This has a lower melting point than the purer metal on top, and the mixing brings all to a more liquid state, thus apparently increasing the temperature. Thus, adding pig iron, when the bath is overoxidized, or adding iron ore when the reactions are slow, will often have the effect of raising the temperature materially, as all experienced open-hearth operators well know—although some of them do not know the reason.

The silicon or silica from the stock forms with the oxidized manganese and iron from the bath a double silicate of iron and manganese, the slag. It may be assumed that in melt-

ing down the stock, all the silicon and manganese, and from 35 to 45 per cent. of the total carbon in the charge is oxidized. This, of course, can only be approximated, being affected by furnace conditions, character of stock, flame, etc.

In order to illustrate the method of calculating the charge of a furnace, assume that 35 per cent. of the carbon is oxidized

TABLE I

Elements	Pig Iron Per Cent.	Steel Scrap Per Cent.
Carbon.....	3.75	.20
Silicon... ..	1.50	.01
Manganese.....	.60	.50

during melting; and that about .8 per cent of carbon is desired in the melted bath; and that the pig iron and scrap to be used, analyze as in Table I.

6. Finding the Desired Percentage of Carbon in the Charge.—If 35 per cent. of the carbon is oxidized during the melting, then 65 per cent. will be left. Therefore, the .8 per cent. of carbon left after melting, is 65 per cent. of that originally in the charge.

$$\frac{.8}{.65} = 1.23 \text{ per cent. originally in the furnace charge}$$

7. Checking the Accuracy of This Result.—If 35 per cent. of the carbon is oxidized during melting, then 1.23 multiplied by 35 per cent. equals the carbon lost.

$$1.23 \times .35 = .43$$

and 1.23 per cent. of carbon in the charge, minus .43 per cent. lost during melting, leaves .8 per cent. in the melted charge.

8. Finding the Proportion of Pig Iron.—From the desired per cent. of carbon in the bath (1.23), subtract the per cent. of carbon in the scrap (.20); this gives $1.23 - .20 = 1.03$ parts of pig iron required.

9. Finding the Proportion of Scrap.—From the per cent. of carbon in the pig iron (3.75) subtract the desired per cent. of carbon in the bath (1.23); this gives $3.75 - 1.23 = 2.52$ parts of scrap needed.

10. Finding the Percentage of Pig and Scrap. 1.03 parts of pig iron plus 2.52 parts of scrap gives a total of 3.55 parts. Then,

$$\frac{1.03}{3.55} = 30\%$$

$$\frac{2.52}{3.55} = 70\% \text{ (approximately)}$$

$$100\%$$

11. Checking the Accuracy of the Results.—The method used in checking these results is as follows:

$$\begin{array}{rcl} 3.75 \text{ per cent. carbon in the pig iron} & \times .30 & = 1.12\% \text{ carbon} \\ .20 \text{ per cent. carbon in the scrap} & \times .70 & = .14\% \text{ carbon} \\ \text{Total} & & 1.26\% \text{ carbon} \end{array}$$

which is seen to be approximately equal to the 1.23 per cent. carbon desired.

For a charge where a high-carbon steel is wanted, the heat to tap at .8 per cent. carbon and to melt 40 points (40 per cent.) above this, or at 1.2 per cent. carbon. Allowing a loss of .30 per cent. in melting down (with the higher carbon in the charge the percentage of loss will be less, though the amount of carbon lost may be as high or higher), we have 1.2 per cent. carbon $\div .70$ (1.00 per cent. $-.30$ per cent.) $= 1.851$ per cent. of carbon to be in the charge. How much of the same metal and scrap used in the previous heat will be required? According to the first method, we have,

$$\begin{array}{l} 3.75 - 1.71 = 2.04 \text{ parts of scrap;} \\ 1.71 - .20 = 1.51 \text{ parts of pig iron;} \\ 2.04 + 1.51 = 3.55 \text{ parts total;} \\ \frac{2.04}{3.55} = 57 \text{ per cent. of scrap;} \\ \frac{1.51}{3.55} = 43 \text{ per cent. of pig iron.} \end{array}$$

In the preceding calculations the sulphur and phosphorus were assumed to be such as to produce a steel within the limits called for. Both are beyond control in the acid process, the entire amount in the stock going into the finished steel, and hence are readily calculated from the stock and the steel specifications. The lower the sulphur and phosphorus in the stock, the higher is its cost, making it economical to use the least amount of the purer stock required to finish the steel within the required specifications. This will always apply to materials purchased, but in the case of a works using scrap from another department, it will not generally be a consideration.

12. Melting the Charge.—During the time of charging, heating up, and melting the charge, it is usual to carry a smoky flame, or a comparatively reducing one, less air being admitted than is necessary for complete combustion. By this means the charge, especially the scrap, is kept from oxidizing, the pig being largely protected by its impurities. This smoky flame is partially self-regulating as, coming in contact with the cold stock, the temperature is lowered sufficiently to precipitate a part of the carbon before combustion takes place. As already stated, the port construction should be such as to admit the air above the gas. So far as melting is concerned, this is mainly to keep next to the metal a stratum of gas, instead of air which would increase the oxidation. This also keeps the flame from the roof and a relatively cooler stratum next to it. Irregularities on the slopes of the ports, from neglect on the part of the furnace helpers in leaving holes or allowing pieces of brick, etc. to accumulate, may deflect currents of gas or air either vertically or horizontally, so that the flame is streaked, and sections of it may be either strongly oxidizing or reducing, or part of the flame may be directed against the roof or sides of the furnace; even small tongues of flame may start cutting of the roof which soon becomes serious if neglected.

The melting is, in the main, an oxidizing action, though more or less of the oxide of iron formed may later be reduced

by coming in contact with carbon, or silicon, and manganese, if the two latter are in the bath. The metalloids are removed to some extent simultaneously, but silicon and manganese are first oxidized during the melting-down stage, or immediately thereafter. Generally, only about one-third of the carbon is oxidized in melting, owing to its smaller affinity for oxygen under the conditions. In case a charge was made up of stock very low in silicon and manganese, more of the carbon would be attacked while melting; or if very high, more of the two former elements would be left after melting. A certain percentage of silicon is necessary in the charge that the proper slag may be formed. It also produces heat by its oxidation.

The function of the slag is to form a blanket or covering for the bath, protecting it from oxidation and transmitting

TABLE II

Analyses	<i>SiO₂</i> Per Cent.	<i>MnO</i> Per Cent.	<i>FeO</i> Per Cent.	<i>MnO+FeO</i> Per Cent.
1.....	49.5	16.5	30.0	46.5
2.....	47.6	12.1	36.3	48.4
3.....	52.2	23.4	22.5	45.9
4.....	46.2	20.6	28.7	49.3

the heat together with oxygen for the removal of silicon, manganese, and carbon. No definite rule can be given for the amount of slag that should be allowed, but it should be thick enough to protect the metal and not so heavy as to offer too much resistance for the heat and oxygen to reach the bath. An acid slag will usually represent from 6 to 10 per cent. of the weight of the charge. This varies with the percentage of silicon and manganese in the charge and the conditions of melting and working of the furnace. The slag is nearly self-adjusting, or is so within quite narrow limits; that is, a charge too low in silicon (or silica) will have this deficiency supplied by the basic slag formed, taking up silica from the hearth. If it contains too much silica, this will be corrected by the

absorption of iron from the bath. Both are objectionable, as the first scorifies the hearth and may start a cutting of the bottom that will result in holes, and even at times in cutting entirely through. Heats have been lost in this way. The second correction causes excessive oxidation of the bath and a consequent high melting loss. Typical acid slags have the composition shown by the analyses given in Table II.

From the above table it will be noticed that the sum of MnO and FeO is quite constant. The silica does not vary over wide limits, and the necessary bases are governed by the character of the stock. If a charge is low in manganese, the required bases in the slag will be made up by a larger percentage of ferrous oxide, or vice versa. Analysis 2 shows a slag from a heat with low manganese in the stock. Analysis 3 is a slag in which a high manganese stock was melted.

13. Removal of the Metalloids, Etc.—The manganese and silicon are first oxidized simultaneously during the melting-down stage, though traces of both may remain to the last of the carbon. Manganese goes more quickly than it would with a basic slag, because the acid slag absorbs it readily. With an excess of silicon in the charge or with the temperature very high, residual silicon may be left after both carbon and manganese are eliminated. A very high manganese content in the charge may also leave residual manganese in the bath. At very high temperatures carbon is oxidized in preference to silicon or manganese, the latter remaining in the bath. This cannot happen in the open-hearth furnace to the extent possible in the Bessemer converter, as the same high temperature is not reached during the oxidation of the silicon. If the amount of silicon and manganese in the charge is more than is required by the oxygen that can be taken up during melting, then an excess of both elements remains in the bath. If ore is added, they will be oxidized before the carbon is acted on; but if boiled out by the action of the flame, the carbon will be removed along with, or partly before, the silicon. Table III shows the reduction in carbon, silicon, and manganese in two heats.

14. Addition of Ore.—When stock that is too high in carbon is melted, ore is added with the charge to hasten the oxidation of the metalloids. More ore is added after the charge is melted, provided the melter sees from the sample that the metalloids are high. In ordinary practice this means only the oxidation of carbon, as both silicon and most of the manganese will have been removed before melting. However, if the latter remain at this stage, they are first attacked before

TABLE III

REDUCTION IN CARBON, SILICON, AND MANGANESE
IN TWO HEATS

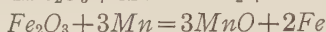
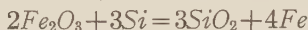
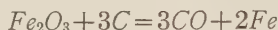
Number of Test	First Heat			Second Heat		
	Carbon	Silicon	Man- gane- se	Carbon	Silicon	Man- gane- se
1	1.00	1.28	.30	1.34	1.600	.40
2	1.00	1.12	.18	1.34	.910	.20
3	1.00	.51	.09	1.34	.260	.06
4	1.00	.33	.04	1.34	.140	trace
5	1.00	.33	trace	1.34	.080	
6	1.00	.05		1.34	.020	
7	.90	.02		1.34	.015	
8	.80	trace		1.28		
9	.55			1.10		
10	.44			1.00		
11	.25			.90		
12	.18			.68		

the carbon is appreciably acted on. The ore used is as free as possible from all impurities.

Its composition may vary somewhat, but as the oxide of iron is the effective agent, the higher the ore is in this, the greater is the amount of work that will be accomplished by a given weight. It is essential that it be in lumps and of sufficient specific gravity to sink through the slag, so as to reach the point where its work—the oxidation of the metalloids—

is to be done. If in a fine condition or of a low specific gravity, part or all of it may remain in the slag with little benefit to the bath, while it will at the same time increase the amount of slag and corrode the lining.

The following reactions take place during ore additions:



By some authorities, it is held that the iron reduced from the ore is only partly added to the bath, the most of it going to the slag. This is purely a theoretical point and of little moment, for, as a matter of fact, if the slag requires oxide of iron, it will take it either from the bath or as it is released from the ore, possibly preferring the latter; but if ore is not added, the necessary oxide of iron will be taken from the bath, consequently the metallic iron reduced from the ore may be assumed as a net gain.

From the reactions given, the weight of ore required to oxidize a given percentage or weight of carbon, manganese, or silicon can be readily calculated:

160 parts, by weight, of Fe_2O_3 oxidize 36 parts of carbon;

160 parts, by weight, of Fe_2O_3 oxidize 42 parts of silicon;

160 parts, by weight, of Fe_2O_3 oxidize 156 parts of manganese.

In practice this is not done even approximately, as conditions in the melting vary to such an extent that any calculation is likely to be worse than useless. If the bath is hot, the ore is acted on rapidly so that the flame has little chance to contribute its share of the oxygen; if the bath is cold, the ore must be added in small quantities, as it lowers the temperature very considerably; under this last condition the oxygen from the flame will effect the greater part of the oxidation. Besides, the action of all heats is not the same; variations in stock, gas, slag, etc. introduce conditions that make even approximate calculations of little value. However, it may be broadly stated that 2,500 pounds of ore will oxidize the carbon in a 75,000-pound charge from 1 to .1 per cent.; or 250 pounds of ore will oxidize the carbon .1 per cent.

in such a charge. This is only an approximation, and about as close a one as can be given. Any silicon or manganese present has the *right of way* over the carbon and must be first satisfied by the ore. In case of a bath high in carbon, the ore first added is much less efficient in oxidizing it than at a later period. This may be partly due to the last traces of silicon and manganese, and partly to the condition of the slag, as its viscosity with high carbon retards the action of the ore.

In Table IV, which is taken from Campbell's "Open-Hearth Process," in the Transactions of the American Institute of Mining Engineers, August, 1893, the average amount of ore

TABLE IV

Elements or Metalloids in the Heat		Pounds of Ore Used						
		1,020	850	None	500	1,000	1,500	2,000
Per Cent.	{ After melting . . .	.54	.64	.36	.18	.32	.61	.57
Carbon	{ Before tapping . .	.08	.08	.08	.08	.08	.08	.08
Per Cent.	{ After melting . . .	.02	.05	.03	.01	.04	.07	.09
Silicon	{ Before tapping . .	.02	.01	.02	.01	.03	.02	.02
Per Cent.	{ After melting . . .	.09	.06	.06	.03	.05	.15	.15
Manganese	{ Before tapping . .	.04	.02	.04	.02	.02	.05	.03

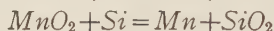
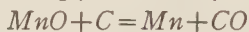
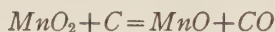
used in boiling down a series of heats and the oxidation of silicon, manganese, and carbon in oreing are given.

15. From a study of this table it will be noticed that the amount of ore is not governed wholly by the percentage of carbon in the bath after melting. Other conditions that affect it are the temperature and the way the heat takes the ore, as the physical conditions of the bath and the slag influence the reduction effected by a given amount of ore. The judgment of the melter determines when ore should be fed, and this may not be done at the proper time, so that a series of tests, however accurate, may be affected by a number of circumstances other than the quantitative work done by the ore. In Table IV is shown one heat melting at .36 per cent. carbon, requiring no ore to bring it to .08 per cent. carbon,

and another heat melting at .18 per cent. carbon requiring 500 pounds of ore to bring it to .08 per cent. carbon. This is explained in the one case by the temperature being too low to work the ore, the flame affecting the oxidation; and in the other by the bath being so hot that the ore is rapidly reduced. The last two heats show considerable silicon and manganese when melted, which will account for part of the ore.

When the metalloids are oxidized by the atmosphere of the furnace, it is believed that the slag acts as a medium for the transfer of the oxygen except of course, in those cases when the violent boiling causes the metal to be thrown above the slag and exposed directly to the oxygen and the carbon dioxide.

The oxidizing action of the slag is performed through the agency of the oxides of iron and manganese. These dissolve in the slag, and, coming into contact with the carbon, silicon, etc., are reduced according to the reactions already given, and also a series of manganese reactions of similar nature, for example:



Subsequently, the *Fe*, *FeO*, *Mn*, *MnO*, etc., may all be oxidized to *FeO*, *Fe₂O₃*, *MnO₂*, etc. by the furnace gases and then again be reduced by the metalloids in the bath. Thus, the slag carries oxygen to the metalloids even in the absence of iron ore added for oxidizing purposes, but this action is usually slower than the direct oxidation by iron ore.

16. Finishing the Heat.—It is important that the heat should be finished with as little oxygen in the bath as possible, and with a non-oxidizing slag, because an oxidizing slag will not only oxidize the bath again, but will also react chemically with the recarbonizer. Therefore, iron ore is not added within $\frac{1}{2}$ hour of the end of the heat. Some melters prefer not to add ore within 1 hour of the end, and all try to maintain at least a gentle boil during the final 30 to 60 minutes, in order to boil as much oxygen as possible out of the metal, and also

to stimulate the reactions, and the contact, between metal and slag which reduce the oxidizability of the slag. The boil also stimulates oxidation by the furnace atmosphere.

17. Finishing Temperatures.—The most essential requirement in a skilful melter is his ability to read temperatures accurately. No apparatus is used for determining this, the eye alone, with the aid of ordinary blue glasses to cut off the intense heat and light rays, shows it within very close limits. The *relative* and *not the actual* temperature is determined, as for all practical purposes this answers fully as well. It is necessary to estimate the temperature of both the melting chamber and the bath. The former is shown by the flame, slag, and, mainly, by the appearance of the side walls and roof. The temperature of the metal can be ascertained only by reaching it direct, and other indications are frequently misleading. The more common method is to try the heat by inserting an iron rod into the bath and stirring it back and forth, noting the rate at which the rod melts; or stir it for a given time, usually $\frac{1}{2}$ or 1 minute, withdrawing it, and observing the way the metal has cut the rod: a clean, sharp end melted to a point indicates a hot bath, while a colder bath will melt the rod much less, but more regularly, rounding it off, for the rod will be built up by the mushy, thick metal. The rod must be thrust quickly through the slag, or the latter will coat and protect it from the action of the bath, so that the indications given by the test will be misleading. In the hands of an experienced melter, the *feel* of the metal as the rod is stirred back and forth gives an idea of the temperature, as it is more limpid and of less viscosity when hot. The surface of the bath will sometimes be as hot as desired, while portions of the bottom will be pasty from partly melted stock.

Another way is to take out a sample of the metal in a small test ladle and pour it into a mold or into a cake on the floor. The character and temperature is shown by the way it pours; its fluidity, or viscosity; the sparks given off, the skull remaining in the ladle; the contraction of the test on

cooling; and general indications that are easily learned in practice, but which cannot readily be described. This test piece is also used to determine the amount of carbon, either by fracture or from drillings taken from it for a rapid-color carbon test.

If the tests are carefully taken and uniform conditions observed in cooling, an experienced eye can usually read the carbon, as shown by the fracture, within 2 or 3 hundredths of 1 per cent. in samples under .2 per cent. carbon. Above this, as the carbon increases, the error in judging by fracture also increases. These tests are taken at intervals until the proper percentages of carbon and temperature are reached, when the tapping hole is opened and the metal run into the ladle. The proper recarbonizers having been added in the furnace or in the ladle, the metal is poured into molds.

RECARBONIZATION

18. General Remarks.—The term *recarbonization*, or *recarburization*, is used to cover more than the mere adding of carbon to the metal; all the ordinary additions, as of manganese and silicon in different alloys, are included. Perhaps a more exact term than recarbonizer would be *additions*, but the former has the sanction of usage. Its purpose is to give the metal the required properties of strength and quality. The recarbonizer is not only for the purpose of leaving certain amounts of carbon, manganese, or silicon in the metal, but also for removing objectionable compounds from it. These are gases and oxides of iron or other elements. Hydrogen, nitrogen, and carbon monoxide are commonly present in steel, rendering it *wild*, that is, causing violent ebullition of the metal in the furnace, ladle, or molds. No theory as to their introduction or elimination is fully accepted, their effect being neutralized or their removal accomplished by the additions. Oxygen, either as the free gas or in the form of oxides—metallic or gaseous—is the chief cause of wild steel, and the recarbonizer, acting as a deoxidizer, reduces these. Silicon to the extent of .10 to .20 per cent. is desirable in practically all steels,

with the possible exception of those which are very low in carbon and which are rarely made in the acid open-hearth furnace.

19. Recarbonizers.—The usual recarbonizers are: (1) Ferromanganese, an alloy of manganese, iron, and carbon; (2) spiegeleisen, the same as the preceding, except the amount of manganese is much less; (3) ferrosilicon, a very high-silicon pig iron; (4) silicospiegel, a very high-silicon spiegeleisen, or a very high manganese ferrosilicon; (5) carbide of silicon (carborundum), an alloy of carbon and silicon produced in the electric furnace; (6) in order to increase carbon only, pig iron, or crushed anthracite coal, or coke breeze in bags is sometimes added with the ferrosilicon, etc.

TABLE V
RANGE OF COMPOSITION OF RECARBONIZING ALLOYS

Alloy	Carbon Per Cent.	Man- gane- se Per Cent.	Silicon Per Cent.	Phos- phorus Per Cent.	Sul- phur Per Cent.	Iron Per Cent.
Ferromanganese	6.5 to 7.0	78 to 82	.3 to 2	.20 to .3	.01	10.0 to 15
Spiegeleisen	4.0 to 5.0	12 to 20	.3 to 3	.15 to .3	.01	72.0 to 80
Ferrosilicon	1.5 to 2.5	1 to 4	10.0 to 20	.10 to .3	.01	75.0 to 85
Silicospiegel	2.0 to 4.0	15 to 20	10.0 to 15	.15 to .3	.01	65.0 to 75
Silicon carbide ..	62.0	trace	35.0	none	none	1.5

The first four are made in a regular iron blast furnace from properly selected ores and with special manipulation of the furnace and special burden.

Table V gives analyses showing the usual range of composition of recarbonizing alloys.

20. Alloys above 20 per cent. of manganese are usually classed as ferromanganese; below this, spiegeleisen. The standard ferromanganese is 80 per cent. manganese, and little else is used until we come to spiegeleisen, 20 per cent. Owing to the conditions of manufacture, sulphur is never beyond a few thousandths of a per cent. Phosphorus is governed by the ores, but should not exceed .3 per cent., and this gives from .002 to .003 per cent. of phosphorus in the steel.

Carbide of silicon has only been used a few years, and finds application as a source of carbon and silicon, especially in the manufacture of steel castings. It is always added in the ladle, and produces a violent reaction if any considerable quantity is used. Its advantages are that a smaller amount is required for the same increase in silicon or carbon, but that the temperature of the steel is somewhat increased instead of lowered, as in the case of the metallic alloys. This increase is due to the heat developed by the combustion of silicon and carbon, but mainly to the fact that the decomposition of the compound releases a large amount of heat.

21. Recarbonization in the Furnace.—This method has certain advantages and drawbacks, as compared with making the addition in the ladle. With the heat ready to tap, the recarbonizer is thrown into the furnace and is allowed a few minutes to melt and mix with the bath. It is claimed for this practice that the manganese is more thoroughly mixed, the bath is more thoroughly deoxidized, the temperature of the metal is not lowered, and the metal is quieter and less likely to irregularities in casting. Against this claim there is said to be a greater loss of manganese, silicon, etc., than when the recarbonizer is added to the ladle. The loss will depend on conditions of the bath and time in the furnace before tapping. A bath containing a large amount of oxygen will oxidize more manganese or silicon than one nearly free from solid or gaseous oxides. A higher temperature, with other conditions constant, will also cause a greater loss.

FINISHING AND RECARBONIZING AN ACID OPEN-HEARTH HEAT

22. Instructions having to do with the chemical analysis of the furnace product come directly or indirectly from the sales department. These instructions determine the conditions of finishing and recarbonizing. They will specify exactly the percentage of carbon, silicon, manganese, etc., required in the steel, and the limits above which the phosphorus and sulphur cannot go. The carbon, silicon, and man-

ganese are arranged in the recarbonizing; the phosphorus and sulphur must be limited by choosing the stock melted in the furnace. In general, there are four grades of steel which may be ordered.

23. Dead soft steel, of under .22 per cent. of carbon, for special wire, or other purposes. (Only a limited amount of such steel is made in the acid open hearth.) Such dead soft steel is usually made as low as possible in silicon in order to avoid the hardening effect of silicon on the metal, and usually moderately high in manganese, in order that the manganese may perform the deoxidizing work which is usually divided between manganese, silicon, and carbon. The deoxidizing work in this instance is even greater than when making steel or higher carbon content, because the boiling out of the carbon charges the metal with more oxygen, and also because the lower the carbon is reduced the more absorbent for oxygen the bath becomes. Finishing the acid open-hearth heat under these circumstances involves boiling until the carbon is down to about .06 to .08 per cent.; then a little ferromanganese is added in the furnace, and the heat is tapped as soon thereafter as possible. More ferromanganese is thrown into the ladle as soon as there is enough metal therein to keep it off the bottom.

The purpose of this procedure is as follows: The manganese added in the furnace while a gentle boil is going on, acts most effectively to drive oxygen out of the bath. However, a large waste in manganese results; about 50 per cent. of the manganese so added finds its way into the slag. Therefore, all of the ferromanganese used should not be added in the furnace, because this practice would be too costly. Of the manganese added in the ladle, about 85 per cent. finds its way into the steel, and, for commercial reasons, this is the most advantageous practice.

24. Low-carbon steel, of about .15 to .22 per cent. of carbon, is used for steel castings, etc. This grade of steel is made in much the same manner as is dead soft steel, with two chief exceptions: It is boiled down to about .12 to .18 per

cent. carbon, instead of .06 to .08 per cent.; and a goodly amount of silicon is added in order to avoid the blow-holes to which steel is subject unless silicon or aluminum has been used to *kill* it. Blow-holes, while not serious in steel that is to be rolled, make steel castings unfit for most uses. In this practice it is not so necessary to add ferromanganese in the furnace, and the ferromanganese and ferrosilicon are often added together in the ladle. It is not necessary to use as much ferromanganese, because the silicon helps the deoxidation work, and because 85 per cent. of the manganese added in the ladle goes into the steel. About 65 to 70 per cent. of the silicon added in the ladle finds its way into the final steel.

25. Medium carbon steel, of .25 to .35 per cent. of carbon, is used for structural shapes, axles, etc. Steel of this grade may be made in either of two ways: That is, the carbon may be caught on the way down and the boiling stopped when the bath contains about 3 or 4 points (.03 per cent. or .04 per cent.) less carbon than is wanted in the final product; then ferromanganese and ferrosilicon are added in respective amounts to give the desired manganese and silicon to the steel. (The calculations relating to this will be given later.) With these alloys there will be carbon enough to make up the 3 or 4 points lacking.

Again, the bath may be boiled down to a low carbon content and then carbon added, as well as manganese and silicon in recarbonizing. The name *recarbonizing*, in fact, originally came from this practice. Some metallurgists believe that this procedure gives a more uniform distribution, and a more exact regulation of the metalloids. Some also believe that the strong reaction brought about by the use of so much carbon, more effectively rids the bath of oxygen. Others maintain, however, that boiling the carbon down to the low point puts more oxygen in the bath than is removed by the carbon addition in recarbonizing. All agree that the longer boiling increases the time of the heat, so it costs less to catch the carbon on the way down. In a heat that is perfectly controlled by the melter, the stock will be so selected that the carbon

will be only slightly above the desired finishing point when the bath is completely melted. Then follows a period of about 30 minutes during which the temperature is raised to the proper tapping point. In this interval the carbon will be boiling off very gently. Then comes tapping and recarbonizing. The final finishing temperature of the steel will be such that it will pour nicely into the molds and leave only traces of *skull* in the ladle. This temperature is not the same for all grades of steel, because the lower the steel in carbon, etc., the quicker it will freeze and form skull; also the longer the time of pouring, the hotter it must be at the beginning. It is good practice for the melter to take careful note of the skulls left in the teeming ladles, and to compare this with his practice in respect to temperature. Dead soft steel should leave the furnace above 2,700° F. The higher the carbon, the cooler it may safely be.

Returning now to the question of recarbonizing medium carbon steel: The carbon may be increased either by melting pig iron in the bath just before tapping, or else by throwing pig into the ladle, along with the ferromanganese and ferro-silicon, or else by throwing bags of anthracite coal in crushed form, or of coke breeze, into the ladle. In the use of pig in the furnace, about 80 to 90 per cent. of its carbon will be absorbed by the steel; in its use in the ladle, 95 per cent. will be absorbed. In the use of crushed anthracite or coke breeze in the ladle, only about 45 per cent. of the contained carbon will be absorbed. All these figures will be lowered when the bath or slag are seriously oxidized. One argument given in favor of the practice of melting pig in the furnace, for recarbonizing purposes, is that the pig added in the ladle may not melt and distribute itself regularly through the bath. It is customary in some plants to add liquid pig iron for recarbonizing, where such is available from cupolas, blast furnaces, etc.

26. High-carbon steel contains more than .40 per cent. carbon. In the acid open-hearth furnace it is almost universally the custom to catch the carbon on the way down to

make this steel, to avoid the addition of large amounts of carbon during recarbonizing. If liquid pig iron is available, it may be added in the calculated amount just previous to tapping, or cold pig iron may be melted in the bath. But the addition of very large percentages of carbon in the form of anthracite or coke breeze is unwise or impracticable.

27. Use of Aluminum.—Metallic aluminum is very generally used for quieting basic steel and, to some extent, acid steel also. It acts as a deoxidizer and belongs under recarbonizers in the general use of the term. While a given amount of silicon will combine with more oxygen than the same amount of aluminum, the latter has a much greater affinity for oxygen under the conditions and is therefore the more powerful deoxidizer; but it is the least apt to remain in the steel if oxides or free oxygen are present. It is always added in the ladle or molds, from 2 to 5 ounces per ton being used. If much above this is added, it causes too rapid solidification and defects from piping and cracking. In addition to removing gases and making the steel quiet, it has the property of rapidly permeating the entire mass of the steel, which causes other elements to alloy more uniformly, preventing or lessening segregation; it gives sounder ingots, and slightly increases the strength of the steel, but increases the depth of the piping.

Caution must be employed in the use of too much aluminum, because it sometimes remains in the steel in a sort of cloud, or fog, of Al_2O_3 . These tiny specks, because of their abundance in one locality, sometimes form a plane of weakness, and defective steel has been traced to this cause.

28. Chromium.—Chromium is added in the form of a ferrochrome alloy, containing perhaps 70 per cent. of chromium, and is usually added in the furnace, because it does not go much into the slag. It may be assumed that 80 per cent. of the contained chromium goes into the metal. In a sense, chromium is not a recarbonizer, because it is not added for the same reason that carbon, silicon, manganese, etc. is added. However, it is added during the general recar-

bonization period of manufacture, but the purpose of adding it is to make one of the so-called alloy steels. Nickel, copper, vanadium, etc., are all added to make special steels, but we may treat the process of incorporating them in the steel at this point for convenience.

29. Vanadium.—Vanadium is added for the purpose of removing oxygen that has escaped the action of manganese, etc. It has a powerful affinity for oxygen and must be added after the other elements (metalloids) have completed their work. It is, therefore, added for the same reason as manganese or aluminum, but is added only in special cases, to make steels of special grade. It is used in the form of a ferro-vanadium alloy, the product of electric furnaces containing perhaps 40 per cent. of vanadium. About enough of the alloy is added to represent .25 to .40 per cent. of the weight of the steel, but the dissolved oxides act upon it so powerfully that seldom, if ever, is more than .15 per cent. of it found remaining in the metal.

30. Nickel.—The cheapest way to make nickel steel is to use scrap containing nickel. If then, the finished bath still requires some nickel to bring it up to grade, it may be added in the furnace any time after melting, but long enough before tapping to insure its complete melting. Less than 2 per cent. of it will be lost no matter when added.

31. Copper.—Copper should also be added at least 20 minutes before tapping, but its melting point is lower than that of nickel. The amount of copper is also very small compared with that of nickel used, so it melts more readily. From .1 to .2 per cent. of copper in steel is believed to reduce corrosion, or rusting, in boiler tubes, pipes, etc.

RECARBONIZING CALCULATIONS

32. Ferromanganese Addition.—In order to calculate the weight of ferromanganese that must be added to the ladle from an acid open-hearth furnace to produce a steel containing .50 per cent. of manganese, the following assump-

tions are made: The heat weighs 200,000 pounds and contains no residual manganese; the ferromanganese contains 80 per cent. of manganese; and 85 per cent. of the manganese in the ferromanganese goes in the steel.

Then, 200,000 pounds of steel $\times .50$ per cent. of manganese = 1,000 pounds of manganese in the steel; 80 per cent. of manganese in the ferromanganese $\times 85$ per cent. of it absorbed by the steel = 68 per cent. of the ferromanganese which becomes the manganese content of the steel. Therefore, the amount of ferromanganese to be added to produce a steel containing .50 per cent. of manganese is

$$1,000 \div .68 = 1,471 \text{ pounds}$$

33. Checking the Calculation.—If 1,471 pounds of ferromanganese, containing 80 per cent. of manganese is used, then 1,177 pounds of manganese will be added. If 85 per cent. of this goes into the steel, then 1,000 pounds of manganese will go into the steel. Therefore, the percentage of manganese added to the steel is

$$1,000 \div 200,000 = .50 \text{ per cent.}$$

34. Silicon.—In order to get .20 per cent. of silicon in steel, how much ferrosilicon of 15 per cent. grade must be added? Assume that the heat weighs 200,000 pounds, and has no residual silicon, and that 70 per cent. of the silicon in the ferrosilicon goes into the steel.

Then, 15 per cent. of silicon in the ferrosilicon $\times 70$ per cent. of it absorbed by the steel = 10.5 per cent. available for steel content; 200,000 pounds of steel $\times .20$ per cent. of silicon therein = 400 pounds of silicon in the finished steel. Therefore, the amount of ferrosilicon to be used is

$$400 \div .105 = 3,810 \text{ pounds}$$

35. Checking the Calculation.—If 3,810 pounds of ferrosilicon is used and it contains 15 per cent. silicon, then 571 pounds of silicon will be added. If 70 per cent. of this goes into the steel, then 400 pounds of silicon will go into the steel. Therefore, the percentage wanted in the bath is

$$400 \div 200,000 = .20 \text{ per cent.}$$

36. Carbon Additions.—Using the preceding examples, and assuming that 45 per cent. of the carbon added dissolves in the steel, the weight of carbon which will go into the steel with the ferromanganese and the ferrosilicon is calculated as follows:

1,471 pounds of ferromanganese $\times$ 7 per cent. carbon = 103 pounds of carbon; 3,810 pounds of ferrosilicon $\times$ 2 per cent. carbon = 76 pounds of carbon. Then, the total carbon added is $103 + 76 = 179$ pounds; 45 per cent. of the carbon dissolves in the steel; therefore, the amount of carbon in the steel is $179 \times .45 = 80$ pounds, and the per cent. of carbon added is

$$80 \div 200,000 = .04 \text{ per cent.}$$

Consequently, a bath of the weight and other characteristics described in the preceding calculations, which contained .15 per cent. of carbon when tapped, would contain .19 per cent. of carbon after the ferromanganese and ferrosilicon have been added.

37. Residual Silicon.—If stock containing much silicon is used, and if the temperature of melting is high, as much as .10 per cent. of silicon might be left in the bath at the end of the operation. This will naturally affect the calculation. For example, if .20 per cent. of silicon in the steel is desired, and there already is .10 per cent. present as residual silicon, then only .10 per cent. more need be added.

38. Manganese Calculation When Ferromanganese Is Added in the Furnace.—Suppose that it is decided to add 500 pounds of ferromanganese in the furnace before tapping, and the remainder in the ladle, how much must be added in the ladle if the steel is to contain .40 per cent. manganese? Assume that the heat weighs 200,000 pounds and contains no residual manganese, that the ferromanganese contains 70 per cent. of manganese, that 50 per cent. of the manganese in the ferromanganese added in the furnace goes into the steel, and that 80 per cent. of the manganese in the ferromanganese added in the ladle goes into the steel.

Then, 200,000 pounds of steel $\times$.40 per cent. of manganese desired therein = 800 pounds of manganese to be dissolved;

500 pounds of ferromanganese added in the furnace contains $500 \times .70 = 350$ pounds of manganese; 50 per cent. of this dissolves in the steel. Therefore, the weight of the manganese that dissolves in the steel in the furnace is $350 \times .50 = 175$ pounds; 800 pounds of manganese wanted minus 175 pounds added in the furnace leaves 625 pounds to be added in the ladle; 70 per cent. of manganese in the ferromanganese $\times 80$ per cent. of it absorbed by the steel $= 56$ per cent. of the ferromanganese which becomes manganese in the steel; and the amount of ferromanganese to be added in the ladle is

$$625 \div .56 = 1,116 \text{ pounds}$$

39. Checking the Calculation.—Ferromanganese to the amount of 500 pounds is added in the furnace; the ferromanganese contains 70 per cent. of manganese, half of which goes into the steel. Then, the weight of manganese dissolved by the steel in the furnace is $500 \times .70 \times .50 = 175$ pounds. In the ladle there is added 1,116 pounds of ferromanganese, which contains 70 per cent. of manganese, and 80 per cent. of this manganese is dissolved by the steel. The weight of manganese dissolved by the steel in the ladle is therefore $1,116 \times .70 \times .80 = 625$ pounds. The total weight of manganese dissolved in the furnace and in the ladle is, then, $175 + 625 = 800$ pounds. The desired percentage of manganese in the steel is therefore

$$800 \div 200,000 = .40 \text{ per cent.}$$

THE BASIC OPEN-HEARTH PROCESS

40. Introductory.—The basic process, either the open-hearth or the Bessemer, differs from the acid process in that stock higher in phosphorus and sulphur is treated and basic materials, usually lime, are added, to give a slag that will retain phosphorus and sulphur in solution. As previously explained, the only difference in the apparatus used is that the hearth is made of a basic instead of a silicious material. The idea should be clearly grasped that the hearth performs no office in effecting the purification—the dephosphorization and desulphurization. It is necessary to have the hearth either of a basic or neutral material, so that the slag will not react with it.

41. Advantages of the Basic Process.—The advantages of the basic process are that purer steel, as far as phosphorus and sulphur are concerned, may be produced, and cheaper stock used. These two statements might seem to be conflicting, as a better or purer material would not be expected from inferior stock. This view retarded the growth of the basic process to a great extent, as many users of steel refused to believe that steel made from impure materials was as good as that made with purer stock.

It is also to be noted that the basic slag is more highly oxidized than is the acid slag; therefore, basic steel is more apt to contain the objectionable impurity, oxygen. Also rephosphorization or desiliconization, or both, are liable to occur during the teeming of a basic heat, thereby introducing an uncertainty in the final composition of basic steel. The present methods of manufacture, however, both from a metallurgical and engineering standpoint, make basic steel equally as well adapted as acid steel for almost every purpose. The furnace, except the hearth, and all accessories are identical with the acid process, and the steel is made from pig and ore or pig and scrap, with a lime addition, with or without ore, as in the acid.

HEARTH MATERIALS

42. Neutral Materials.—It is immaterial whether the hearth is of neutral or basic material, but in present practice it is altogether the latter, and this is all that need be considered. The neutral materials that have been used in hearths are carbon in bricks or mixed with refractory materials, such as bauxite and chromite. None has been entirely successful.

Carbon is unsuitable mainly because of the affinity of the metal for it. It is readily absorbed—the hearth thus being gradually destroyed. It would be an ideal material to resist the action of the slag, but the above objection renders its use out of the question.

Bauxite is one of the most refractory substances known, but its excessive shrinkage at high temperatures causes it to crack and unfit it for this purpose. It is practically neutral under all conditions. It has these two most essential points: It has been thoroughly burned and shrunk before being used, but this, by causing loss of combined water, destroyed its plasticity, which is important.

Chromite is highly infusible and withstands basic conditions in a high degree. In fact, the chief point against it is its infusibility, as it is difficult to sinter or set a bottom with it, so that erosion takes place, not because of refractoriness, but because of the mechanical condition in which a hearth is left.

43. Basic Materials.—The strictly basic materials for the hearth are lime, dolomite, and magnesite.

Lime is the cheapest and most widely distributed material; it occurs in the form of limestone, or calcium carbonate, CaCO_3 . Theoretically, burned lime, or calcium oxide, CaO , is well suited for hearths, but practically it does not answer, as it slakes so rapidly on exposure to the air that it cannot be kept in stock. A bottom made of it when heated would partially crumble into dust, owing to the driving out of the water and gas, and would be rapidly worn away by the metal.

Dolomite, or magnesian limestone, $\text{CaMg}(\text{CO}_3)_2$, was originally much used owing to the high price of magnesite. It

is abundant in many and relatively cheap in all localities, and when thoroughly burned does not absorb enough moisture to slake for some time. It has been used with tar, rosin, or other material to bind it until set by the heat. The tar is generally discarded now and the material thrown in without any binding agent. It has been made into bricks and the bottom built up with them. Bottoms have also been made by ramming in loose layers. The best method, however, is the same as making up a sand bottom, by sintering in thin layers, allowing time for each stratum to be thoroughly set.

Magnesite, or magnesium carbonate, $MgCO_3$, when calcined to MgO , is the ideal material for basic hearths so far as our present knowledge of refractories goes. Practically all hearths now put in are made of it, although many dolomite hearths are still in use. Its high cost barred and retarded its use for a number of years in the basic process, but discoveries of large deposits in Austria and Greece have lessened the cost greatly. Magnesite lasts so much longer than dolomite, that it is more economical in the end to use it, but the lining below the surface layer, and the patching is commonly done with dolomite. The Grecian magnesite is much purer, and is generally considered to make the better brick, but it is not adapted for making bottoms, as it is too refractory when used alone. To lower its fusing point by the addition of silica, clay, or oxide of iron is too uncertain in results and does not give a bottom having as good physical qualities to resist wear and erosion as the calcined natural Austrian magnesite. The bottom is made the same as one of dolomite or silica, by setting successive layers and generally using a little basic slag to make it flux; clay may be used in place of slag, but the latter is preferable.

On the bottom of the basic hearth two courses of magnesite brick are generally laid or one of magnesite and one of chromite brick. This is done to offer greater resistance to the metal or slag should the bottom be cut through. The side walls also are built of magnesite brick until near the top of the lining, sometimes only to the foreplate, or two or three

courses above. Silica brick are used above the magnesite in the side walls and for the roof. Formerly it was considered necessary to have a neutral or passive joint between the two, as it was held that the silica and magnesite would flux. Any of the neutral or passive substances above mentioned answer, but chromite is best adapted. The idea that they will flux in the side walls has been proved erroneous, and silica brick are often laid directly on the magnesite brick with no neutral body between. It is only essential that the side walls be protected from the basic slag, and this is easily accomplished by extending the magnesite lining above the highest normal slag level.

44. Charge.—In regard to the metal, the charge differs from an acid charge only in that more pig iron can be, and usually is, melted. The reasons are both commercial and metallurgical. Basic pig iron is cheaper than acid (low phosphorus) pig iron. The basic process is more oxidizing than the acid process, because the basic slag is intrinsically a more oxidizing slag; the carbon dioxide from the limestone acts as an oxidizing agent on the elements in the bath and also there is less objection to mixing ore with the original charge, because ore (Fe_2O_3) is a basic substance. Therefore, more oxidation is effected during the melting-down stage. Limestone, or burned lime, is added with the charge to form the basic slag. Technically, it makes no difference which is used, so far as forming a basic slag and removing phosphorus is concerned, but the furnace is the cheapest place to burn the stone; hence, the raw limestone is almost universally used. The pig iron should be as low as possible in silicon. A maximum of 1 per cent. is the highest allowed in good practice and usually it does not exceed .75 per cent. As each pound of silicon in the pig iron requires, roughly, 15 pounds of limestone, the importance of having the silicon at the lowest possible point is apparent. The above ratio is only an approximation, as silica may come from other sources, and the percentages of phosphorus and sulphur largely determine the amount of lime to be charged. A large lime charge is objectionable from its

increased cost; but especially as it means an increased amount of slag, so that the time of melting is lengthened, cutting down the output of the furnace; extra fuel is used to melt the slag and afterwards to get the heat through the heavy covering; it is harder on the furnace, as the fine dust is carried against the silica roof and over into the checkers—cutting the one and clogging the other.

45. There is somewhat greater variation in the method of charging than in the acid process. In the best practice all the limestone is charged on the bottom; then comes the ore, the pig iron is placed on this, and then the scrap. Some prefer to charge part of the scrap on the bottom, then all or a part of the limestone, the pig iron, and the remainder of the scrap last. Others charge only a part of the stone, and as slag begins to form from the oxidation of silicon and manganese, add burned lime as needed to keep the slag sufficiently basic. The chief advantage with the lime on the bottom is the better protection it affords the latter; also, as the stone is decomposed, the CO_2 and CaO coming through the pasty mass help mechanically to bring action to the bath. The only objection to placing all the stone on the bottom is that it sometimes sticks to the basic lining, partially filling up the melting space. With proper attention from the furnace men, there should be no serious trouble from this source. A rod is used to loosen the lime as it begins to come off the bottom.

In recent practice, molten pig metal taken directly from the blast furnace or from a mixer has been used with entire success and the practice is being adopted wherever blast furnaces are operated in connection with basic open-hearth furnaces. The use of hot metal, as it is called, is not adapted to the acid open hearth, as the silica hearth of the latter is rapidly scorified by charging either the molten iron, or steel scrap, directly on the bottom. In the basic process the bottom is protected by the limestone and then by whatever steel scrap is used. The molten pig iron is poured in from a ladle, carried by an overhead traveling crane, on top of the rest of

the charge. The advantage of hot metal is that heats are made in much less time, thus increasing the output per furnace. The scrap is usually heated until it begins to *drip*, or the hot metal may be poured in soon after the scrap is charged.

In the first experiments, trouble was encountered in keeping up the bottom, but the preceding method of charging was adopted and little or no difficulty results. From two to four heats extra per week can be made by using hot metal, which results in an increase of from 15 to 25 per cent. in the output.

46. Calculation of the Charge.—The weights of pig, scrap, stone, and ore vary with local conditions, the character of the stock, and of the steel to be made. Whether pig or steel scrap is the more abundant or cheaper determines the percentages of these within extreme limits—from 100 per cent. of one, or the other may be used. The more pig used, other conditions being the same, the more limestone is required to keep the slag basic because of the silicon to be oxidized; or the higher in silicon, the more stone. Phosphorus and sulphur also require lime for their absorption; the purity of the limestone largely determines the amount needed. If high-carbon steel is wanted, more carbon must be charged, which in this case is furnished by the pig iron. The quantity of ore used is determined by the metalloids to be oxidized; a high pig charge means increased ore since it is the pig iron that contains the metalloids, and a minimum of pig, no ore.

Besides the above relations being considered independently, allowance must be made for their relation to each other; that is, a large amount of stone and ore cannot be charged together, owing to the excessive foaming produced. The percentage of manganese present influences the amount of CaO required.

The following is a charge for a basic open-hearth furnace of 90,000 pounds capacity:

45 per cent. of pig iron will equal 40,500 pounds.

ANALYSIS OF THE PIG IRON

Silicon.....	.75%
Sulphur.....	.05%
Carbon.....	4.00%
Phosphorus.....	.60%
Manganese.....	.75%

55 per cent. of steel scrap will equal 49,500 pounds.

ANALYSIS OF THE SCRAP

Silicon.....	trace
Sulphur.....	.06%
Carbon.....	.12%
Phosphorus.....	.10%
Manganese.....	.50%

8 per cent. of limestone will equal 7,200 pounds.

ANALYSIS OF LIMESTONE

Silica.....	1.000%
Calcium carbonate.....	95.700%
(Calcium oxide).....	(53.600)%
Ferric oxide and alumina.....	.800%
Magnesium carbonate.....	2.400%
(Magnesium oxide).....	(1.150)%
Phosphorus.....	.006%
Sulphur.....	trace

2 per cent. of iron ore will equal 1,800 pounds.

ANALYSIS OF THE IRON ORE

Silica.....	2.500%
Iron.....	67.500%
Alumina.....	.950%
Phosphorus.....	.042%
Sulphur.....	trace
Calcium and magnesium oxides.....	.300%

The total charge usually includes only the pig iron and scrap, but sometimes the iron content of the ore used is figured in. A portion of the pig iron is usually replaced with cast-iron scrap, owing to the lower cost of the latter.

Owing to the great variability of conditions, no exact rule can be given for calculating the charge. It seldom happens

that all the stock is sufficiently uniform to get more than an average analysis of it. This is generally the case with scrap iron. In the charge just given, in order to show the calculation, it is assumed that the materials are uniform.

In the slags given in Table V, the proportion of calcium and magnesium oxides to silica is very variable. Such wide divergences are due to the other elements in the slag and to the conditions of melting. But, fortunately, even with the rest of the composition the same, the ratio of calcium and magnesium oxides to silica may vary greatly, so that no exact calculation is necessary, or even possible. The basis of the calculation is the silica, calcium oxide, and phosphorus. The phosphorus becomes calcium phosphate, $Ca_3(PO_4)_2$, and ferrous phosphate, $Fe_3(PO_4)_2$, in the slag, but sufficient calcium oxide is allowed for all the phosphorus. Assuming that this is done, we have $3CaO$ to $2P$, or 168 parts, by weight, of calcium oxide to 62 parts, by weight, of phosphorus; or 2.7 pounds of calcium oxide to 1 pound of phosphorus, this being merely the theoretical amount required for the reaction. In practice, about 3 pounds of calcium oxide is allowed for 1 pound of phosphorus. Somewhat more calcium oxide is allowed for the silica, about 4 pounds to 1 pound of silica. Applying this to the actual working charge just given, we have the following calculations:

CALCULATION FOR PHOSPHORUS

40,500 lb. pig iron at .6% phosphorus = 243.0 lb. phosphorus

49,500 lb. scrap at .1% phosphorus = 49.5 lb. phosphorus

Total charge contains 292.5 lb. phosphorus

(The small amount of phosphorus in the ore would be disregarded.)

292.5×3 (the ratio of CaO to P) = 877.5 pounds of calcium oxide required for the phosphorus.

CALCULATION FOR SILICON

40,500 pounds of pig iron at .75 per cent. of silicon = 303.75 pounds of silicon. $Si : SiO_2 = 28 : 60$, or the weight of silicon $\times 2\frac{1}{2}$ = weight of silica.

303.75 lb. silicon in pig iron $\times 2\frac{1}{7} = 650.9$ lb. silica
 7,200.00 lb. limestone at 1% $SiO_2 = 72.0$ lb. silica
 1,800.00 lb. ore at 2.5% $SiO_2 = 45.0$ lb. silica

Total charge contains 767.9 lb. silica

767.9×4 (the ratio of CaO to SiO_2) = 3,071.6 pounds of calcium oxide required for the silica.

Calcium oxide required for the phosphorus = 877.5 lb.

Calcium oxide required for the silica = 3,071.6 lb.

Total calcium oxide required for silica

and phosphorus = 3,949.1 lb.

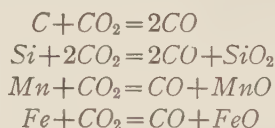
To find the amount of limestone required, MgO is figured as CaO ; therefore, the stone is considered as containing $53.6 + 1.15 = 54.75$ per cent. of available CaO . Then, $3,949.1 \text{ pounds} \div .5475 = 7,213$ pounds of limestone required; or in practice, 7,200 or 7,225 pounds would be taken.

47. Lime Addition.—The function of the lime, as already explained, is to form the basic slag without which dephosphorization and desulphurization are impossible. The amount of lime required depends primarily on the amount of silicon or silica in the charge; and after satisfying the SiO_2 with an excess of lime, a further basicity is required to unite with phosphorus and sulphur, depending on the percentage of the latter elements present. From 90 to 98 per cent. of the phosphorus in the charge is removed. Sulphur is more difficult and uncertain to control; frequently over half is readily removed, while, again, when conditions appear almost the same, a reduction of 10 per cent. will be hard to obtain.

Manganese is a great help in the removal of sulphur, and basic pig iron often contains as much as 2 per cent. of manganese for this purpose. It might seem that iron oxide would be a better base from which to make a basic slag than is calcium oxide or lime. There are two objections to this: one is commercial, iron oxide is more costly than is lime; the other is that carbon easily reduces iron oxide from slag or elsewhere, and therefore the basicity of an iron oxide slag would fluctuate, which would cause serious irregularities in the process. This

principle of the ready reducibility of ferruginous slags is availed of in the Talbot and Monnell open-hearth processes, the former especially making a beautiful application of this reaction. Calcium oxide and magnesium oxide are not reduced at the temperature of the open-hearth furnace, and, therefore, form stable bases for slag constituents.

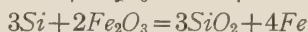
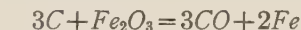
Magnesium oxide has been used, but not so effective, because a slag high in magnesia is less fusible, more viscid, and refractory (which means more fuel), and is harder on the furnace. Lime, either as limestone, $CaCO_3$, or as burned lime CaO , is the essential basic addition. Economy determines in which form this limestone is added, but it is almost always used as the raw stone. The use of the latter affects the process by the carbon dioxide liberated by the decomposition of the carbonate. This carbon dioxide acts as an oxidizing agent on the metalloids of the bath, thus allowing a larger percentage of pig iron to be used, which is an advantage when this is cheaper stock than steel scrap. The following reactions show the relation of the carbon dioxide as an oxidizer:



By some, the carbon monoxide working through the partly melted mass is said to cause foaming of the slag due to gases passing through it. Foaming is not only caused by carbon monoxide, but also by other gases, and by silicon under certain conditions of temperature and working. There is then danger that the metal and slag may be carried over into the ports, boil out the doors, or that the slag may come in contact with the silica side walls of the furnace, cutting these and introducing silica into the slag. About the only remedy for foaming is by checking the action of the bath—if from carbon, shutting off the gas until the action lessens; if from silicon, making the slag more basic by the introduction of burned lime.

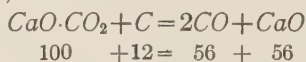
48. Use of Ore.—Ore is used in the basic just as in the acid process, both by charging with the stock and by feeding

after melting, to oxidize the carbon, etc. The amount charged depends on the percentage and character of the pig iron used and how low the carbon is to be boiled down. The reactions of the ore are as follows:

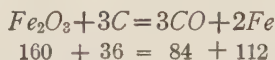


The reactions do not take place immediately, as there are a number of intermediate steps, but the ultimate results are the same. As has been stated, the carbon monoxide causes foaming and limits the amount of limestone and ore that can be charged. Both the carbon dioxide from the stone and the ore Fe_2O_3 are reduced by the carbon of the bath, the other metalloids being first oxidized. The ore, however, produces less carbon monoxide than does the limestone, for the same amount of carbon oxidized.

(1) Limestone,



(2) Ore,

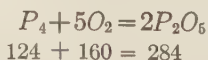


From the above equations it is seen that for every atom of carbon oxidized by the limestone, or more strictly by the carbon dioxide, 2 molecules of carbon monoxide are produced; while in the case of ore 3 atoms of carbon produce only 3 molecules of carbon monoxide. Or in the first case, each carbon atom gives 2 volumes of carbon monoxide; in the second, each carbon atom shows only 1 volume of carbon monoxide produced. So that for a given amount of carbon monoxide produced, twice as much carbon is taken from the bath with ore as with stone. Nearly as much difference is shown in their oxidizing effects, as 100 parts of limestone take 12 of carbon, while 160 parts of ore take out 36 parts of carbon [see equations (1) and (2) above]; $53\frac{1}{3}$ parts, by weight, of ore accomplishes the work of 100 parts of limestone, or the ore is $1\frac{7}{8}$ times as efficient an oxidizer of carbon.

49. There is a great difference, also, in thermal conditions, resulting from the reactions shown by the above equations. The first, reducing carbon dioxide to carbon monoxide, is endothermic (absorbing heat); the second is in two phases, endo- and exothermic (liberating heat); the first phase consists in reducing the Fe_2O_3 ; and in the second phase heat is developed when the oxygen reduced from the ore combines with the 3 atoms of carbon. The second phase produces more heat than the first phase absorbs, so that the net result is a gain in heat.

Limestone has been termed a refrigerating agent, owing both to the distillation of its carbon dioxide and the action of this on the metalloids to form carbon monoxide. The terms refrigerating agent and calorific agent as applied, respectively, to limestone and ore must not be taken too literally, for in practice these effects do not stand out so prominently as the above might indicate. That the facts are as stated can be proved by calculations of the heat absorbed and developed by the reactions given. In practice, this may be modified or obscured by other factors, but the net results are as given.

50. Melting, Etc.—Melting on the basic hearth is an oxidizing action in the main with the same forces at work as on the acid. In addition, there are several relations changed or modified, and the essential difference of a basic slag carried, to effect the removal of phosphorus and sulphur. The oxygen consuming power of the metalloids has already been given. In basic practice phosphorus is added to the list according to the reaction



One part, by weight, of phosphorus unites with 1.290 parts of oxygen; or 1 part of oxygen with .775 part of phosphorus. The oxygen-absorbing power is only slightly less than that of carbon (1.333), or 1 part phosphorus is equivalent to .968 part of carbon.

In general the most easily oxidized elements are first burned. In acid practice it was shown that the formation of oxide

of iron was necessary to combine with the silica to form the slag. In basic practice we have the lime to combine with the oxidized silicon, and silica originally in the stock, so that there is not the same call for iron to be oxidized, but iron oxide is always present in basic slag. Just why the necessary conditions cannot be fulfilled by the other bases is not so apparent. In general slags seek to absorb or combine with whatever increases fluidity and fusibility, and this may explain why ferrous oxide is taken up, its presence giving greater fusibility. With an increase of lime in the slag, the percentage of iron decreases, as a rule, but there are a number of conditions modifying this. The amount of manganoous oxide, MnO , and phosphorus pentoxide, P_2O_5 , greatly affect the fluidity of the slag and lessen the necessity for ferrous oxide.

51. The matter of viscosity of the slag is of the utmost importance in basic open-hearth work, and is a function of the composition and temperature. A too viscid slag will not readily transmit the heat and oxygen of the gases to the bath, so that the oxidation of the metalloids is delayed, while a too fluid slag will cut the basic hearth, even if the excessive fluidity is not due to silica, although the latter is usually the cause. The remedy for such a slag is to render it basic and this must be done promptly, for at the high temperature it rapidly attacks the hearth. Burned lime or dolomite may be used, but the former is much better and is almost always employed, as magnesia renders the slag viscid and requires greater heat for the same fluidity. Frequently the lime comes up and remains on the surface without dissolving. This condition, of course, is due to a deficiency of silica for the lime to readily combine with; it is generally an advantage rather than otherwise—that is, within the limits of sufficient silica in the charge to form a slag with the bases. To cut up the lime in such a case, or to render a too basic slag more fusible, fluorspar, calcium fluoride, CaF_2 , is employed by throwing a few shovelful (from 25 to 200 pounds) on the slag or lime.

Silica or a silicate will, of course, thin the slag very quickly, but it is a remedy that may cut both ways and attack the

lining or lower the basicity of the slag, so that dephosphorization will not take place completely or allow some of the phosphorus to return to the bath. Fluorspar is much more efficient, and gives fluidity without lessening the basicity of the slag. The reaction is rather obscure, but the most probable explanation is the formation of a double fluosilicate. Manganese ore is sometimes used for the same purpose and is very efficient; it has the additional advantage that the manganese oxide in the slag acts as a desulphurizing agent also. The increased fluidity from manganese is not due to any reaction with the silica or lime, except that a more fusible compound is introduced into the slag. This latter may also partially explain the action of calcium fluoride.

52. Basic Open-Hearth Slag.—Chemically, the slag is a silicate of calcium, iron, and manganese. Magnesia is

TABLE VI

Limit	SiO_2	$CaO + MgO$	FeO	MnO	P_2O_5
Minimum ...	10	45	10	5	5
Maximum ...	20	55	25	15	15

always present both from the limestone, and the dolomite or magnesite of the hearth and that used for patching; the amount furnished from the limestone is almost always much less than that from the other sources. Alumina is also present in amounts usually varying from 2 to 6 per cent., its source is the same as magnesia; these two compounds are not to be considered essential, but rather incidentally present from the nature of the case.

No fixed limits can be given for the composition; as previously stated, the two essentials are *fluidity* and *basicity*. The former first, that it may flow freely from the furnace with, or immediately after, the metal, so as not to fill up the hearth; second, that the reactions may take place without too much resistance from the slag, so that the "boil" will

not be checked when the metalloids are oxidizing. Basicity is necessary, first, to retain the phosphorus and sulphur of the charge; second, to preserve the basic lining of the hearth.

The ordinary limits of composition of a good slag are given in Table VI.

If the silica runs much below 10 per cent. the slag is too viscid to perform its function properly, unless sufficient fluidity is furnished by liquefying elements, especially manganese and phosphorus. If above 20 per cent., there is always danger of cutting the bottom and a failure to purify the bath, but in case of very low phosphorus in the charge the silica may exceed the maximum given without harm. High ferrous oxide generally goes with low silica, and vice versa, but there are many exceptions to this. The calcium and magnesium oxides will depend on the other bases and on the phosphorus pentoxide, though primarily on the percentage of silica. The MnO and phosphorus pentoxide result from the manganese and phosphorus in the charge. By a consideration of the conditions existing, it will be seen that ferrous oxide is the only compound regarding which the slag has any choice; the others are forced on it, as it were—they are in the charge and must be gotten rid of by way of the slag, while the ferrous oxide is the poise by which the slag is adjusted. This relation cannot always be shown from a given slag, as conditions, besides that of composition, enter into and make the matter somewhat involved.

53. It is held by some authorities that an increase of calcium oxide means a decrease of ferrous oxide. This is explained by the increased basicity given by the calcium oxide, the slag not requiring so much ferrous oxide, which being feebly held, is readily reduced by the bath carbon. This view is doubtless correct for slags containing enough manganous oxide and phosphorus pentoxide to impart the necessary fluidity without absorbing more ferrous oxide for this purpose, but in the case of slags where the manganese and phosphorus are low, an increase of calcium oxide means more ferrous oxide in the slag to give the necessary fluidity,

probably due to the formation of a ferrate of calcium. This latter condition may be taken as the usual one, and, as a general proposition, an increase in calcium oxide calls for more ferrous oxide in the slag. In a slag low in calcium and magnesium oxides, the ferrous oxide will be higher to make up the basicity, so that either a high or low percentage of calcium oxide in the slag may require more ferrous oxide. These relations are not conflicting, although at first they may appear so. In a normal basic slag fluidity and basicity are not antagonistic; fluorspar and manganese ore, both of which are basic, are also used to give fusibility to the slag. Excessive fusibility may come from silica, but such a slag would not be a normal basic one.

54. As the charge begins to melt, the slag first formed is short of bases and takes up ferrous oxide, in greater proportion than is held later, to give the necessary basicity; this excess of ferrous oxide is reduced by the bath carbon as the lime combines with the slag. With the limestone charged on the bottom, there is more or less tendency for it to stick to the hearth. As the charge becomes semifluid and pasty, rods are used to poke the stone loose, otherwise it may accumulate and build up the bottom to such an extent that the hearth will not hold the regular charge.

55. In ordinary practice all of the slag is held in the furnace until the heat is tapped, when it runs out after most of the metal and forms a covering for it in the ladle, protecting it in a great measure from loss of heat. Sometimes only a part of the slag remains in the ladle, the remainder running off into a slag hole under the tap hole. When the steel is poured the ladle is dumped by means of a chain hooked to its bottom and operated by an auxiliary trolley on the bridge of the ladle crane.

Tapping a part of the slag immediately after melting has been followed to some extent, but this is not usually an advantage. One practice was to melt with insufficient lime and tap off the slag before it had time to scorify the hearth, the object being to get rid of a large part of the silica without satisfy-

ing it with lime. As such a slag is quite acid, there is always danger of scorifying the hearth excessively, besides losing steel in running it off, and more time is lost in repairs than the procedure justifies. Another practice is to run a very limy slag and tap this off after melting, when it contains most of the silica and phosphorus of the charge. This is less objectionable than the first, but has some of its drawbacks and is not ordinarily good practice, except when very silicious and phosphoric stock is melted and a large amount of lime must be carried, thus giving an abnormal quantity of slag.

The tilting furnace is best adapted for a preliminary removal of slag, and this is one of its chief advantages. With it the

TABLE VII
AVERAGE COMPOSITION OF BASIC FINAL SLAGS

Number of Slag	<i>SiO</i> ₂	<i>CaO</i>	<i>FeO</i>	<i>MnO</i>	<i>P</i> ₂ <i>O</i> ₅	<i>MgO</i>	<i>Al</i> ₂ <i>O</i> ₃
1	18.30	50.25	14.91	4.85	3.43	6.00	1.96
2	14.60	50.04	10.20	7.15	6.50	8.07	2.62
3	19.20	45.62	9.04	9.60	2.98	10.28	3.28
4	29.43	39.07	14.61	8.00	5.28	5.20	
5	8.70	51.90	23.45	7.25	11.00	3.70	
6	12.20	41.20	18.30	5.30	12.60	6.40	
7	14.25	39.97	13.18	10.84	9.51	8.49	
8	9.85	43.46	14.81	8.26	15.38	4.23	
9	8.50	45.30	18.25	8.00	12.40	4.50	
10	10.90	42.70	12.09	10.26	13.70	5.58	

slag is decanted off to whatever extent is desired, although it is not possible to pour it all off, as some steel would come with it.

The average composition and ordinary variations of basic slags are shown in Table VII.

The above are all representative slags except No. 4, which is exceptional from the high percentage of silica. It is given because such slags are occasionally met with, but imperfect purification of the metal or excessive scorification of the

hearth generally results. The sulphur exists in the slag as sulphide, principally as CaS , the percentage usually being from $\frac{1}{4}$ to 1 per cent. CaS .

56. In conclusion, it may be said that the essentials of the slag are silica, calcium oxide, and ferrous oxide in proportions to give a fluid, basic slag. The presence of manganous oxide is highly desirable to give fusibility and to desulphurize, but it is not an essential; it is, however, always a constituent, depending on its percentage in the stock. The phosphorus pentoxide is present as a result of the oxidizing action and the basicity of the slag; this is the fundamental principle of the basic process.

Even under best conditions of working the slag always scorifies the hearth somewhat. The slag line, or shelf, requires patching after each heat, burned dolomite or magnesite being used, generally the former, as it is cheaper, also as it sets more quickly and is thus more permanent. Holes frequently are left in the bottom after the heat is tapped; the metal and slag must be bailed or splashed out of these with rabblers (heavy iron hoes) and the holes filled with magnesite, a little slag usually being added to increase the fusibility, so that it will set quicker.

The amount of slag produced in basic work is necessarily much greater than in acid, and usually ranges from 8 to 20 per cent of the weight of the charge. This depends on the amount of slag-forming elements in the stock, the amount and quality of limestone used, and the melting practice.

57. Dephosphorization.—The removal of the phosphorus takes place partially during the oxidation of the other metalloids, as a rule, or may be complete before the carbon is all burned, but the greater part of the manganese and all of the silicon is oxidized before dephosphorization can be finished. It is probable under certain conditions that the phosphorus is simultaneously oxidized with the silicon. Owing to the conditions of melting it is practically impossible to obtain data that will accurately set limits within which dephosphorization occurs. The essential thing, of course, is to have suf-

ficient lime present to form not only a basic slag, but to leave enough in excess to absorb the phosphorus pentoxide formed. The phosphorus in the slag exists as a phosphate of iron or calcium. The purpose and exact office of ferrous oxide, with respect to phosphorus, is not understood, but a certain amount seems to be required.

58. In melting stock low in phosphorus the elimination may be essentially complete during the melting period, while with high phosphorus the percentage of removal will be much

TABLE VIII

ANALYSIS SHOWING ELIMINATION OF PHOSPHORUS
DURING MELTING

No. of Sample	Initial Phosphorus in Charge	Per Cent. of Phosphorus After Melting	Amount of Phosphorus Removed	Per Cent. of Phosphorus Eliminated in Melting	Accompanying Slags			
					<i>SiO₂</i>	<i>FeO</i>	<i>P₂O₅</i>	<i>CaO</i>
1	3.00	.755	2.245	75.00	10.41	17.37		48.56
2	2.18	.629	1.551	71.00	12.79	4.41	23.50	43.07
3	2.29	.849	1.441	63.00	12.68	4.05	21.83	42.18
4	1.42	.563	.857	60.00	11.10		16.05	
5	.55	.282	.268	49.00	30.26	10.08	5.99	45.26
6	.55	.297	.253	46.00	31.30	10.98	3.72	41.45
7	.55	.378	.172	31.00	34.05	18.45	3.08	35.09
8	.55	.464	.086	16.00	34.37	6.57		
9	.19	.009	.181	95.00	13.02	24.21		
10	.19	.032	.158	83.00	14.09	27.09		
11	.19	.072	.118	62.00	22.93	11.16		
12	.19	.105	.085	45.00	25.34	6.66		

less, though the actual amount may be greater. There is no relation between the amount eliminated during melting and that present in the charge; with apparently uniform conditions as to stock, conditions of melting, etc., wide variations are shown in practice. Some of the practical obstacles in determining the dephosphorizing conditions referred to above are the uncertainty as to whether all lime has come off the bottom when the heat is melted; the kind and arrangement

of the stock; the character of the flame; changes in the slag due to irregular stock and varying percentages of ferrous oxide. Table VIII shows the phosphorus removed during melting, together with partial analyses of the accompanying slags. These are given as examples met with in practice and not intended that any general deductions should be drawn as to dephosphorization, as many conditions affecting this cannot be shown. The first four given show unusually high phosphorus in the charge; in this case the elimination was increased by a large amount of ore charged with the heat. The second four show a much lower elimination with a smaller percentage of phosphorus in the charge; in this case a deficiency of lime, as shown by the high silica in the slags, will mainly account for this.

The last four show a low phosphorus charge for basic practice with elimination nearly complete in one case; these also show the removal greater with lower silica in the slag.

59. When the heat is melted a test is taken and broken to show the melter the approximate carbon content and whether or not the phosphorus is low. The latter can be told by the fracture, the same as the carbon, but with much less certainty, so that this is generally determined by analysis. After the lime is all up, the melter adjusts the slag (entirely by the eye); if it is too acid, burned lime is added to bring it to the proper consistency; if it is too basic, it is thinned with fluorspar or manganese ore. With the proper slag, if much phosphorus remains in the bath after melting and the carbon is not too low, it will generally be oxidized by the time the carbon is boiled down to the desired point. In case the phosphorus should not be removed when the carbon is practically all out, it is usually necessary to add pig iron, which lowers the temperature and brings action on the bath by introducing metalloids to be oxidized. This procedure is mainly required, however, because the slag covering a carbonless bath rapidly takes up ferrous oxide, but the presence of carbon neutralizes this action or reduces the *Fe* from any ferrous oxide formed.

The thermal conditions accompanying oxidation of phosphorus favor its removal during melting, as it enters the slag at a comparatively low temperature. This does not mean that it is not removed at a high heat also, but it is better to have the phosphorus go off at a low heat and the carbon follow at a higher temperature.

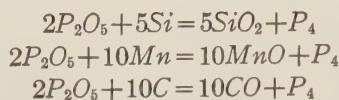
In good basic practice, the phosphorus is reduced to less than .04 per cent. in the finished steel, and not infrequently in the regular practice the steel shows but .01 to .02 per cent. of phosphorus. Depending on whether high or low phosphorus stock is melted, this shows an elimination of 90 to 99 per cent. Table IX shows the percentage of phosphorus in six samples of finished steel, that in the charge and in the slags, and represents current practice.

PRINCIPLES OF DEPHOSPHORIZATION AND REPHOSPHORIZATION

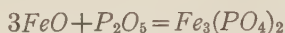
60. As sugar is dissolved in tea, or salt in water, so phosphorus is dissolved in steel. From the operating standpoint it is immaterial whether it is dissolved as Fe_3P , or FeP , or merely as elemental phosphorus distributed through the body of the bath. How then is it to be removed? The rule, which was given under iron ore smelting, may be repeated here as follows:

61. The Fundamental Rule of Metallurgy. Reduced elements dissolve in the metal, and oxidized substances dissolve in the slag, provided they can be retained in the oxidized condition.

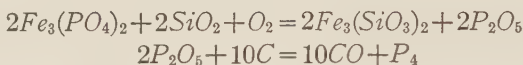
62. Application of This Rule to Phosphorus.—If, therefore, phosphorus can be oxidized and retained in the form of P_2O_5 it can be held in any slag that will absorb it. But P_2O_5 is a weak compound, surrounded by elements ready to rob it of its oxygen.



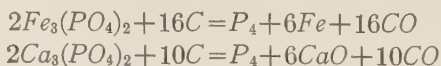
Now, P_2O_5 is a weak acid radical, and if it can be made to combine with some strong base, it has some protection from its despoilers.



But even this combination may be broken up by silica, which is a stronger acid radical than is P_2O_5 . Then the helpless P_2O_5 will again become a prey to one of the elements which has a stronger affinity for oxygen than has phosphorus. For example:



To avoid this reduction of phosphorus a slag may be maintained so rich in lime as to satisfy fully the acid activity of silica and thus prevent it from robbing the phosphoric acid of its basic radical. This is the purpose of maintaining a basic slag with never less than 35 per cent. of lime, nor more than 20 per cent. of silica. Such a slag will readily absorb phosphorus as fast as it is oxidized, but it must not be forgotten that the oxidation will have to occur before the slag can dissolve the phosphorus. A slag which is both strongly basic and strongly oxidizing will perform both of these functions, but its basic character must not be disturbed. If the silicon in the metal is oxidized to silica in such an amount as to reduce the basicity of the slag, then rephosphorization of the metal may occur. Likewise, if FeO (which is a basic radical) is reduced to Fe during the furnace reactions, this may so reduce the basic character of the slag as to make it drop some of its dissolved phosphorus. It sometimes happens even during a violent boil, that carbon will reduce phosphorus directly from a slag which is not very strongly basic:



63. Rephosphorization During Recarbonizing.

The preceding reasons explain why recarbonizing may never take place in a basic furnace, because not only is SiO_2 formed by oxidation of silicon in the recarbonizer, but also the added

carbon, silicon, and manganese act on the slag and reduce FeO from it. Therefore, it is imperative to separate the slag from the metal as much as possible before recarbonizing takes place, but also it is desirable to cool the slag and thus decrease its chemical activity with the metalloids.

64. Rephosphorization During Teeming.—The ladle into which the bath is tapped is customarily lined with acid bricks. If the metal and slag are very hot, there is some reaction between the slag and ladle lining which adds silica to the former. The metal also slowly absorbs oxygen, and thus some additional silica is formed, which also decreases the basicity of the slag. Especially in the teeming of basic open-hearth castings, which usually takes a long time to complete, the final metal is lower in silicon and higher in phosphorus than the metal first teemed.

65. Dephosphorization and Temperature.—Phosphorus can be oxidized in melted steel at any temperature if enough oxidizing agents are present. But, at the low temperatures of usual steel baths, phosphorus has a greater affinity for oxygen than has carbon, while at higher temperatures carbon has a greater affinity than phosphorus. Therefore, rapid dephosphorization may be effected either by maintaining a low temperature in the furnace (as in the puddling process), or else by first removing the carbon (as in the basic Bessemer process), thus leaving nothing present to interfere with oxidation of phosphorus. But it is not wise to remove the carbon in the open-hearth furnace until we are quite ready to tap, because this leaves the iron exposed to severe oxidation, even though phosphorus be present. Phosphorus is not as good a protector of iron from oxidation as is carbon. It is, therefore, customary to remove the phosphorus in the early stages—preferably by the time the bath is melted by using large amounts of lime and ore with the initial furnace charge. This is the easier because the temperature is lower during that period. If, however, the bath melts high in phosphorus, or else low in carbon, it may be necessary to increase the carbon by pigging up.

66. Desulphurization.—Throughout the manufacture of iron and steel, sulphur is the most difficult element with which the metallurgist has to contend. One by one the others have been controlled and a way found for their elimination, generally by surrounding them with such conditions that they are made to do useful work. The reactions involved in their removal furnish a large amount of heat in all the processes, and in some, all of the heat used in converting the liquid pig iron to steel. In the acid Bessemer process the oxidation of the silicon, carbon, and manganese gives all the heat required; in fact, it may furnish too much for proper

TABLE IX

ANALYSIS SHOWING PHOSPHORUS IN FINISHED STEEL,
ELIMINATION, ETC.

No. of Sample	Initial Phosphorus in Charge Per Cent.	Phosphorus in Ingot Per Cent.	Phosphorus Eliminated Per Cent.	Accompanying Slags				
				Per Cent. of SiO_2	Per Cent. of FeO	Per Cent. of P_2O_5	Per Cent. of MnO	Per Cent. of CaO + MgO
1	3.000	.036	98.8	13.98	4.68	16.62		52.73
2	1.350	.040	97.0	8.28	13.47	11.37	6.98	55.77
3	.190	.012	94.0	15.04	21.02			
4	.100	.005	95.0	18.30	15.30	3.43	4.85	56.25
5	1.000	.015	98.5	12.20		4.80		
6	.820	.020	97.6	10.60				

working. In the basic Bessemer, the oxidation of phosphorus is the chief source of heat. In both the acid and the basic open-hearth processes, the oxidation of the impurities furnishes a large amount of the heat. Sulphur is the only one of the ordinary impurities in pig iron that has not been fully utilized in some process. Both basic methods remove a part of it, but cannot be said to control it, as results are irregular and any large reduction cannot be counted on with certainty.

67. Manganese and lime are the only agents, chemically, that are used; temperature is a potent factor in eliminating

it, and there seems to be no limit, except what the furnace will stand, at which a high heat is not an advantage.

The action of manganese and lime is as follows:

(a) Manganese effects reduction: (1) By carrying out sulphur as explained in Art. 69; (2) by the use of manganese ore, which, as reduced, adds manganese to the bath, acting as in (1), or, if incorporated directly in the slag, is reduced from the latter during decarbonization and dephosphorization; (3) by the addition of ferromanganese or spiegeleisen to the bath, which act as in (1), but are more effective for the same amount of manganese.

(b) A limy slag absorbs sulphur, the only conditions being extreme basicity and high temperature. In connection with lime, calcium chloride has been used; its use is covered by a patent known as the *Saniter process*, from its developer. At the time of its introduction (1892) great claims were made for its efficiency and much was expected from it. It did not reach any general application, and is not used today in America, and by only a few plants in England, where it originated. The fumes from the calcium chloride had a damaging effect on the furnace roof. In using calcium chloride, an unusually limy slag is carried, the function of the chloride apparently being to furnish fluidity, the extra basicity of the slag likely taking care of the sulphur without any direct help from the calcium chloride. Any other agent that increases the fusibility without lowering basicity, thus allowing a more limy slag to be carried, is as efficient.

Fluorspar assists in desulphurizing in the same way. It is improbable that it has any direct action, but by giving the necessary physical condition to an otherwise too viscid slag it may be classed as an indirect desulphurizer.

68. With high sulphur in the charge more is removed, under otherwise similar conditions, than with low sulphur stock. This is apparently due to the greater tenacity with which smaller percentages of all the elements remain in the bath. The non-uniformity of removal is mentioned above. As a general statement, it may be said that one-third of the

sulphur in the charge is eliminated in good basic practice. This is without any special effort or losing time for adjusting the slag by any of the additions given above. By the latter course, a removal of 50 to 75 per cent. can be effected regularly; and this is frequently reached in regular working, without particular pains, except as noted, but cannot be relied on. Whether it is an economy to get a high elimination of sulphur depends on the cost of the purer stock, as the more sulphurous, the more time is consumed, thereby reducing the output. The extra basic additions are harder on the furnace, on account of dust carried over to the ports and checkers and the higher working temperature employed. The cost of the extra additions is of some moment, but usually less than the two preceding points.

69. Manganese effects removal of sulphur by metallic manganese, whether the latter is added as such or whether it is reduced from ore by the action of silicon and carbon, taking the sulphur from its combination with iron, or solution in the bath, forming sulphide of manganese, which is mostly absorbed by the slag. It may also occur that part of the manganese sulphide is decomposed by the oxidizing action of the slag and exposure to the flame, the sulphur burning to SO_2 and the manganese returning to the bath to take up sulphur again, or it may form manganous oxide at once. Lime may combine with sulphur directly in the presence of carbon or by reacting with the manganese sulphide.

The reactions of lime and manganese with sulphur are as follows:

1. $Mn + FeS = MnS + Fe$ (absorption by metallic manganese).
2. $MnS + O_2 = SO_2 + Mn$ (loss of sulphur in waste gases).
3. $MnS + CaO = CaS + MnO$.

That part of the sulphur is oxidized and lost in the waste gases (it seems most probable as shown by reaction 2) is indicated by the fact that the sulphur in the slag and the finished

steel does not always account for all in the initial charge. If using producer gas, from .005 to .015 per cent. of sulphur will be absorbed from this source. Natural gas does not increase the sulphur.

Considerable sulphur is generally lost during melting, but no regularity attends this. In endeavoring to get accurate data as to sulphur, more obstacles are in the way than with any other element. Some of these are: Sulphur absorbed from the gas; that lost by volatilization; the difficulty of obtaining the exact amount in the charge, as it will vary more

TABLE X

Calculated Sulphur in Charge Per Cent.	Sulphur After Melting Per Cent.	Sulphur in Ingot Per Cent.	Per Cent. Eliminated
.085	.070	.050	41.2
.120	.100	.045	62.5
.070	.050	.020	71.4
.280	.220	.086	69.3
.060	.040	.030	50.0
.050	.030	.025	50.0
.040	.030	.025	37.5
.045	.035	.030	33.3
.035	.030	.030	14.3

than any other element, and unless elaborate sampling of the stock is done, there is greater discrepancy; most important and exerting the greatest influence, are changes and influences that are not fully understood, and from the nature of the case seem impossible to control. Among the latter are variations in the slag, character and arrangement of the stock, temperature, some of the melting conditions, etc.

Table X gives results from regular basic practice of sulphur elimination without any attempt to analyze the various causes in individual cases.

FINISHING AND RECARBONIZING A BASIC OPEN-HEARTH HEAT

70. The whole subject of recarbonization and of recarbonization and finishing, as treated under the acid open hearth, should be studied in connection with the basic open hearth. Every principle and calculation there set forth applies to the basic process, but additional difficulties are encountered in recarbonizing in the presence of a basic slag. For example, it is difficult and hazardous to add carbon, silicon, or manganese in the presence of a basic slag charged with phosphorus or sulphur, because the chemical reactions occurring are liable to upset the equilibrium and precipitate phosphorus, or sulphur, or both, from the slag, so that they reenter the metal. Silicon not only reduces, but, after its oxidation to silica, tends to acidify the slag, and thus introduce further dangers, for only a very basic slag will retain phosphorus and sulphur. Cautious metallurgists, therefore, seldom add any of these metalloids in the basic furnace, and they also hold back the slag as much as possible from the ladle, where the recarbonizing is taking place. Furthermore, the basic metal and slag are much more charged with oxides than are the corresponding acid products. There is a slight loss in silicon and a slight increase in phosphorus in the steel after recarbonizing and during teeming, due to gradual oxidation of silicon in the steel and its replacement of phosphoric acid in the slag. Therefore, the steel first teemed will be different in analysis from that teemed at the end. Allowance should be made in determining the recarbonizer.

In the basic process at least equal caution should be observed as to finishing with a non-oxidizing slag and bath as low in oxides as possible. Inevitably the basic slag will be more oxidizing than the acid slag.

71. Recarbonizing Calculations.—In the basic process there will be a greater loss of manganese from ferromanganese than in recarbonizing the acid steel. While this loss will depend on the degree of oxidation, the softness of the heat, and the temperature of the bath, it can usually be

assumed that about 80 per cent. of the manganese will be absorbed in the steel. Likewise, about 65 per cent. of the silicon in the ferrosilicon will get into the steel. It cannot be expected that there will be any residual silicon in the basic steel, as a rule, but there will usually be .10 to .20 per cent. of residual manganese. This is due to the fact that more manganese is usual in the basic stock used, and because the basic slag does not attract the manganese as much as does the acid slag, nor as much as the basic slag attracts the silica.

72. Residual Manganese.—The amount of ferromanganese that must be added to a basic heat when .15 per cent. of residual manganese is present in the steel as tapped is calculated as follows: Assume that the heat weighs 200,000 pounds, that the ferromanganese contains 80 per cent. of manganese, that 80 per cent. of the manganese goes into the steel, and that .40 per cent. of manganese is desired in the steel.

Then, as the ferromanganese contains 80 per cent. of manganese and 80 per cent. of the manganese goes into the steel, the percentage available for steel content is $.80 \times .80 = 64$ per cent. The percentage of manganese to be added is $.40 - .15 = .25$ per cent. The amount of manganese to be absorbed by the steel is therefore $200,000 \times .25 = 500$ pounds, and the amount of ferromanganese to be added is

$$500 \div .64 = 781 \text{ pounds}$$

73. Checking the Calculation.—In the heat of 200,000 pounds there is .15 per cent. of residual manganese, therefore the amount of manganese in this is $200,000 \times .15 = 300$ pounds. The amount of manganese in the 781 pounds of ferromanganese added is $781 \times .80 \times .80 = 500$ pounds. The total manganese is therefore $300 + 500 = 800$ pounds. The percentage of manganese is

$$800 \div 200,000 = .40 \text{ per cent.}$$

74. Sulphur and Phosphorus.—Strange as it may seem, sulphur is sometimes added to a basic bath, because steel too low in that element is more liable to be *wild* in the

molds. Phosphorus is sometimes added to lessen the weldability of steel that is too great. Thus, in making steel for tin plate, which is doubled back upon itself several times during rolling, in order to roll the sheets very thin (the plates being pulled apart before tinning), a steel too low in phosphorus will stick together too hard. The sulphur is added in the form of stick sulphur, of which about two-thirds dissolves in the steel. It is added in the ladle. The phosphorus is also added in the ladle in the form of a pig iron high in phosphorus. About three-quarters of the contained phosphorus dissolves in the steel.

MANUFACTURE OF STEEL

Serial 2053C

(PART 3)

Edition 1

MODIFICATIONS OF THE OPEN-HEARTH PROCESS

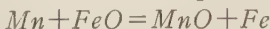
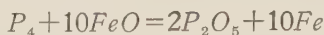
DESCRIPTION AND METHODS OF OPERATION

THE TALBOT PROCESS

1. Assume a tilting basic open-hearth furnace of extra large size, holding about 300,000 pounds of melted metal, and upon this bath a slag highly basic with lime and highly oxidizing with iron ore. The upper surface of the metal will inevitably be oxidized also. The temperature is relatively low in order that phosphorus may be oxidized ahead of carbon. Into this bath is poured about 150,000 pounds of melted pig iron, in two or three separate lots, but as fast as the violent reaction permits. The reaction due to boiling is so violent, in fact, that all the doors of the furnace must be kept open, and flame pours out of them almost like a mouth of the Bessemer converter, although the temperature of the flame is much lower. This action is due to oxidation of carbon:



The violence of the reaction is an indication of the rapidity of the accompanying reactions taking place within the bath, but not resulting in flame:



The silicon goes at once, because of the basic slag ready to absorb it; the phosphorus also goes immediately, because of the low temperature, and much of the manganese and carbon are also oxidized before the new metal is actually incorporated in the original bath. Samples are taken to show the analysis, and carbon is boiled off to the desired point; it should be unnecessary to add for this purpose more iron ore than was used to make up the slag present at the beginning of this operation. While the carbon is being boiled off, the temperature is also raised to the desired tapping point. When all is correct, about 150,000 pounds of metal is poured off into the teeming ladle, and poured into ingot molds, leaving about 300,000 pounds in the furnace. Now a new slag is made up again, as before, and this in itself helps to lower the temperature to the point where a rapid oxidation of phosphorus is secured. The operation is then repeated as before.

2. The chief advantage of Talbot's modification is the possibility of working the pig-and-ore type of process, and securing a rapid purification from all the oxidizable impurities. This is commercially the proper thing to do where pig iron is cheaper than steel scrap. Under reverse conditions of price, the Talbot process would not be advisable. Thus, the great pig-iron centers—England, Pittsburgh, Buffalo, etc.—are the fields of the Talbot process. The pig-and-ore process makes steel out of both pig iron and iron ore, because the ore added to the slag gives up the iron in accordance with the reactions given in the preceding paragraph. Therefore, the yield of the Talbot process, like that of all pig-and-ore processes, is large—say, 105 per cent. or more. This method of making steel is also relatively rapid; the impurities in 150,000 pounds of metal could not be oxidized in so short a time unless the Talbot bath could be used in the manner described. The weakness of the process is the time required to adjust the carbon and the temperature after the other metalloids have been burned out.

3. Duplex Process as Applied to Talbot Furnaces.
In order to overcome this weakness of the Talbot process,

some plants pour into the Talbot bath, not molten pig iron, but liquid steel from the Bessemer converter. From this the silicon, manganese, and most of the carbon have already been eliminated, but slag in the Talbot furnace washes out the phosphorus almost as quickly as the metal pours through it. The temperature is not so low as in the original Talbot process, because there is so little carbon present to interfere with phosphorus removal. Therefore, the steel is ready to pour into the teeming ladle about as soon as the last ladle of converter metal has been poured into the furnace.

THE MONELL PROCESS

4. The Monell process was developed later than the Talbot and may be briefly and to some extent considered as the latter worked in the ordinary stationary furnace, all the metal being tapped out at once. It was worked out at the Carnegie Steel Company's works and is used to a great extent by them. It involves no new principle; in fact, the same method was tried in the early history of the basic open-hearth process, but Mr. Monell has achieved much greater success than ever before reached by the method. As worked at the Homestead plant, limestone and iron oxides (ore, scale, or low-silica cinder) are charged on a basic hearth, heated to partial fusion, and liquid pig iron poured in when the action becomes violent and the metalloids are rapidly oxidized. This action is the same as in the Talbot process—except much less intense—and is due to the slag, containing the excessive amount of iron oxides. The slag is tapped off through a tap hole placed above the level of the metal, but this is not within the easy control obtained by decanting from a tilting furnace, and is one of the objections to the process. Another is, the slag, rich in oxides, corrodes the bottom, if it comes in contact with it, and this cannot be entirely avoided. About the same or a slightly increased output per week is obtained over the same furnace, using pig and scrap. The yield from metal charged is slightly less than in the Talbot. The same stock is available as in the ordinary pig-and-ore open-hearth process or the Talbot.

The low temperature at which the process is worked causes the main part of the phosphorus to be eliminated during, or shortly after, the pouring in of metal. The rest of the phosphorus and the carbon are boiled off thereafter, but the removal of slag during the pouring-in lessens the danger of rephosphorization, and the carbon may be boiled off as fast as the violence of the reaction will permit. This hastens somewhat the usual pig-and-ore process.

BERTRAND-THIEL PROCESS

5. In the Bertrand-Thiel process two open-hearth furnaces are operated as a unit and the metal is transferred from the first, or melting, furnace, called the primary, or refiner, into a secondary, or finisher, furnace. It is the invention of Messrs. Bertrand and Thiel, Kladno, Austria, and has been in successful operation there since 1894. Only one other plant (in England) has been constructed to operate on this system. It may be worked on either the acid or basic hearth, but so far has only been worked on the latter, and is not likely to be used for acid practice.

6. One of the chief advantages of the process is its flexibility, as it may be worked exclusively as a pig-and-ore process or pig-and-scrap with equal advantage and in any available proportions. As in the former process, the refiner is charged with liquid pig iron and enough lime or limestone to furnish a basic slag and ore to oxidize part of the metalloids; the amount of the latter (mainly silicon and phosphorus) in the metal determines the amount of lime and ore to be used. In this furnace all of the silicon is oxidized, approximately 90 per cent. of the phosphorus and manganese, and about 40 per cent. of the carbon. As stated elsewhere, both silicon and phosphorus are oxidized at comparatively low temperatures; this accounts for the removal of these elements in the first furnace. The metal is then transferred to the finisher, into which has previously been charged and heated nearly to the fusing point, about half the quantity of lime, or limestone, and ore used in the refiner.

7. The hot metal, with from 2 to $2\frac{1}{2}$ per cent. of carbon, no silicon, little manganese, and a small percentage of phosphorus, coming in contact with the highly oxidizing slag has the carbon and remaining phosphorus quickly removed. (It will be seen that the oxidation of the metalloids in the Talbot, Monell, and Bertrand-Thiel processes depends on the same principle—the oxidizing power of a basic slag rich in oxides of iron—though applied somewhat differently in each case.) In coming from the first to the second, or finishing, furnace, the slag is skimmed off and very little allowed to enter the latter. As originally worked, the refiner furnace stood on a higher level than the finisher—both being stationary—and the metal ran down a trough. This is not an essential feature of the process, and either stationary or tilting furnaces on the same level may be used, the metal being transferred from one to the other by ladle and crane. The tilting furnace, on the same or a higher level, offers the advantage that the slag may be conveniently handled by decantation.

In case scrap is used, a small amount is charged into the refiner, and the greater part into the finisher, with the stone and ore, and allowed to heat and oxidize somewhat before the refined metal is added. This oxidation of the scrap is not a loss, as it takes the place of some ore, and the carbon and phosphorus reduce it to metallic iron, which is added to the bath.

8. About the same yield as in the Monell practice is obtained—102 or 103 per cent. of the metal charged. An output of 45 heats per week from the two furnaces has been obtained, a greater number than from two furnaces using similar stock worked on the usual system; the tonnage has been much less than from two large furnaces, as only small ones (20 tons) have been used so far; but it is believed that nearly as many heats can be made by using large furnaces—when the tonnage will be greater than that obtained from two of equal capacity—and the operation finished in one furnace. The charge is in the first furnace 2 or 3 hours, and in the second from 2 to $2\frac{1}{2}$. This can be adjusted, however, by changing the point to which the refining is carried.

DUPLEX PROCESS

BESSEMER AND OPEN-HEARTH

9. A weakness of the open-hearth process is the slow removal of the metalloids. The removal of $3\frac{1}{2}$ to 4 per cent. of carbon takes time, because its oxidation results in a gas which swells up the charge so that slag, or even metal, may run out of the doors, unless the metal is very liquid indeed, which means high temperature, with resulting damage to the furnace and to the steel. Therefore, the carbon is diluted by making steel scrap the chief part of the charge, but this only partly remedies the objection, because this steel scrap must be melted. Commercial considerations also enter, as mentioned previously.

While pig iron may be brought molten from the blast furnace, perhaps through the medium of a mixer, it is not practicable to melt steel scrap in a cupola or similar furnace, since by so doing it would again become permeated with carbon. Hot, or melted iron, absorbs carbon very fast when the two are in contact; indeed, *CO* in the gases of steel heating furnaces will give up carbon to the hot steel which is being prepared for rolling. However, pig iron may be blown into a Bessemer converter and brought molten to the open-hearth furnace. In one sense this may be considered as the use of molten steel scrap in the furnace. If then, about four heats of pig iron are blown in a converter (equal to, say 80 tons) and poured successively into a basic open-hearth furnace, and then about 20 tons of molten pig iron from a blast furnace poured in, the equivalent of a pig-and-scrap process, using molten pig and molten scrap, is obtained. The process is, in general, somewhat the same as if the scrap were first piled in the furnace and then liquid pig iron poured on top, but the details are, of course, very different and the operation is more rapid. From the commercial standpoint this type of duplex process is only applicable where pig iron is about as cheap, or cheaper, than scrap.

From the metallurgical standpoint it may be considered as taking advantage of the rapid action of the Bessemer and the dephosphorizing action of the basic open hearth.

BESSEMER AND ELECTRIC FURNACE

10. A principle similar to the one just described may be employed by purifying the metal in a Bessemer converter and then removing phosphorus and sulphur in a basic electric furnace. This is much more costly than the combined Bessemer and open-hearth processes, but makes it possible to take advantage of the *killing* or *dead melting* action of the electric furnace. It also permits sulphur to be removed.

OPEN-HEARTH AND ELECTRIC FURNACE

11. When purifying is done in a basic open-hearth furnace and then the superrefining in an electric furnace, the latter has less work to do, and, in this respect, the duplexing is less costly, because it is the electric furnace which is most expensive to operate. Phosphorus is removed in the open-hearth, and some of the sulphur.

BESSEMER, OPEN-HEARTH, AND ELECTRIC FURNACE

12. The triplex process is employed under special conditions, the electric furnace being used to kill the metal from the open-hearth furnace, and to superrefine it in respect to sulphur.

THE BESSEMER PROCESS

13. Introductory.—The Bessemer process for the manufacture of steel was invented by Henry Bessemer, and patented in England in 1855. It is doubtful if any single invention or discovery has had such a wonderful effect on industry and manufacturing in general. While it became the basis of the modern steel industry, in itself of great magnitude, it is in the development of other industries, made possible by the cheapening of steel, that its full importance is seen. The railroads in particular, in their present development could become a reality only when it was possible to produce steel on the large scale necessary for rails and other parts of the equipment. Steamships and engineering and manufacturing establishments of all kinds are made of it or depend on it for success. In fact, our whole industrial and commercial life may be said to be more dependent on steel than on anything else; but until the invention of the Bessemer process it was impossible to produce steel in sufficient quantities or at a suitable cost to permit its general use. While the Bessemer process has a future, especially in the United States, where suitable ores are available, it is being superseded to a great extent by the basic open-hearth process; and whenever the cost of production by the latter becomes equal to or lower than the Bessemer it will supplant it still further.

14. Bessemer experimented several years before taking out his first patents, which covered the principle of blowing air through or over molten iron. Many other metallurgists had worked on the line of introducing a blast of air to effect the refining of pig iron, but only one other, so far as known, used a vessel or converter and blew the air from the bottom through the liquid iron. While the priority of Bessemer's invention has been questioned, there is no doubt that his work was prosecuted independently and that he was the first to

realize completely the full success of the principle. The other inventor who used this principle was William Kelly, an American, who experimented about the same time as Bessemer, and applied for a patent in 1857; while Bessemer had secured American patents nearly a year before this, the patent office allowed Kelly's claim on the ground of priority of discovery. For several years following this, two companies, representing the Bessemer English and the Kelly American patents, attempted to introduce the process into the United States. Litigation resulted and a compromise was finally effected by the former company taking 70 per cent. and the latter 30 per cent. of the United States royalties. This was only partially in recognition of the Kelly patent, as the latter company had acquired the United States rights to the patents of the Mushet recarbonizing process by the use of spiegeleisen or ferromanganese. This is the only recognition either Kelly or Mushet received for their work on the pneumatic process of making steel, although, unfortunately, the financial rewards of the above compromise did not reach either. Bessemer's apparatus, from a mechanical point of view, was much superior to Kelly's.

Bessemer's experiments covered almost every conceivable method of applying the pneumatic principle—blowing from the top and sides on to the metal or through it; in various kinds and types of fixed and movable vessels, etc. He finally adopted the vessel or converter with the air blown through the metal from the bottom. This type of apparatus, as Bessemer developed it, remains the standard today. Many mechanical improvements tending to increase the speed and convenience of working have, of course, been made, a large number being developed by Alexander L. Holley, when the process was first applied, in America.

15. Bessemer's original idea was to produce wrought iron, but owing to the large amount of gases left in the metal and the lack of a fibrous structure, the blown metal was worthless. At this point his experiments rested for some time and seemed almost a failure. Mushet had previously added and patented the use of maganese in the form of dioxide, under reducing

conditions, and later as an iron and manganese alloy called *spiegel*, or *spiegeleisen*. It was when Bessemer availed himself of this method that good, salable, steel was first made by the Bessemer process.

The first plant built on a commercial scale was at Sheffield, England, the home of the crucible-steel industry. While the chief technical difficulties had been so far overcome as to produce merchantable steel, there still remained the commercial ones of introducing it and overcoming the prejudice of users to a new metal, and setbacks from failures from putting it to uses for which it was not intended, as sometimes, to replace soft iron or harder steel. Its first use was in certain tools, machine parts, etc., and later, in ship building, railroad construction, and the varied kinds of merchant-steel shapes, bars, etc. The great consumption of Bessemer product has been and yet is steel rails. As the process grew in England, it extended to the Continent and the United States.

16. Apparatus Used.—The essential appliance and the one representing the Bessemer or pneumatic principle, is the converter or vessel in which the molten pig iron is transformed from cast iron into steel, or more correctly into blown metal—the recarbonizing being necessary to give the final product, steel. As necessary adjuncts, are cupolas for remelting, or else some means for taking the pig iron direct from the blast furnace; and the necessary cranes, ladles, molds, etc. for handling the iron used and the steel produced. The movements of the cranes, converter, etc., are controlled by hydraulic power, an accumulator keeping up the pressure, which is usually maintained at 500 to 700 pounds per square inch. More recently electric power is used.

17. Cupolas.—The cupola furnace used is shown in Fig. 1. It is the same as the ordinary foundry cupola except that it is larger and is usually placed at a higher level, owing to a different method of handling the iron. The number and size vary with the iron to be melted, but the usual Bessemer plant has from three to six. The height from the bottom to the top of the stack is approximately 40 to 60 feet. The

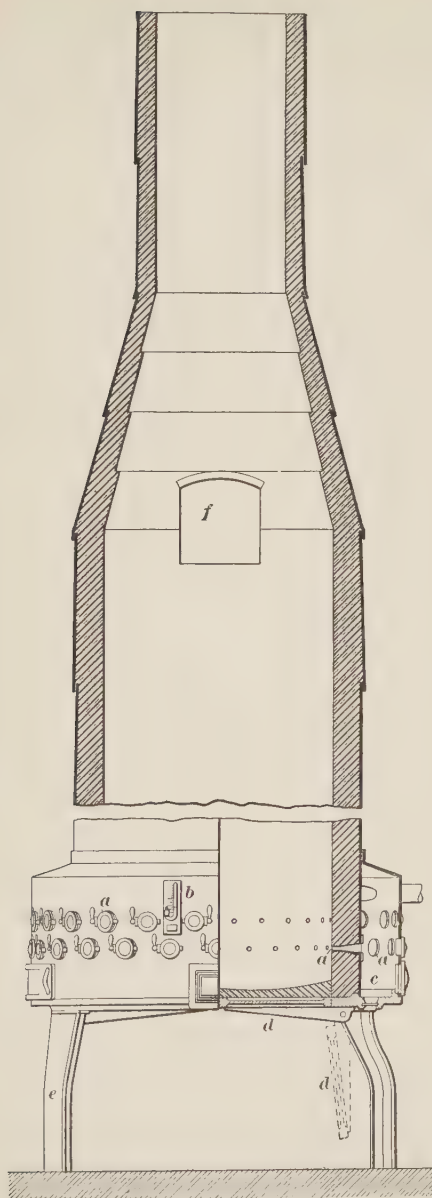


FIG. 1

diameter of the shell (of about $\frac{1}{2}$ -inch riveted steel plate) is from 10 to 15 feet and is lined with firebrick, giving a melting space of 8 to 12 feet in diameter in freshly lined cupolas; they may rest on solid foundations or on iron pillars *e*. All cupolas are arranged with drop bottoms *d*, and are, therefore, always set up some distance above their foundations to allow the doors of the drop bottom to swing down. These are necessary to facilitate the cleaning out of the cupolas at the end of each week, or oftener; they run without repairs from 3 to 6 days, when they become partly filled up and scaffold across, so that the space in the shaft is too small for proper melting. About 25 feet above the bottom of the cupola is the charging floor, where the stock is elevated to be charged into the charging door *f*. As the metal melts it drops to the bottom, whence it runs through the tap-

hole into the ladle. As in all melting furnaces, slag forms; this is removed through a slag hole at a higher level than the iron notch, or tap hole; the space, or well, between the two holes allows the accumulation of melted iron, in case delays occur.

18. Tuyères.—These are the openings (shown at *a*) in the shell and lining, through which air is supplied for the combustion of the fuel effecting the melting. They are either separately connected to the blast pipe or open from a common wind box *c* extending around the cupola. Usually they are made of iron castings curved to fit the inner and outer diameter of the cupola. The opening is oblong and slightly smaller inside than out. The best method is to install tuyères so as to come as near as possible to a continuous opening all the way around the cupola. The best height of the opening will be from 4 to 6 inches; its width will usually be between 5 and 10 inches. This dimension is unimportant from the standpoint of cupola working, but depends only on providing support for the superincumbent lining. Two rows of tuyères is common, because it gives faster melting; sometimes a plurality of rows are installed, but this increases the height of the fuel bed, and therefore the amount of fuel on the bed. The blast is furnished by a blower, or fan, usually placed in the engine room, and has a pressure of 8 to 14 ounces per square inch, as shown on a gauge *b*; the tuyères or main blast pipes are provided with slides or valves for regulating the volume and pressure of blast to suit the various melting conditions, such as the working of the cupola or the amount of iron wanted. The amount of air used is a variable quantity, but is approximately 30,000 cubic feet per ton of iron melted.

19. Lining.—The cupola lining consists of the best grade of fire brick and varies from a thickness of 18 to 24 inches at the bottom, where the greatest wear and pressure come, to 12 inches in the upper part. The abrasive action of the descending charge of pig iron, etc. requires a brick of special quality. The brick are laid up with a thin grout of ganister and clay; patching is done with ball stuff of the same.

20. Fuel.—This consists almost universally of coke, but anthracite coal is used as a partial substitute where it is cheaper; coke, however, owing to its more open structure, which permits the ready passage of the blast and keeps the shaft open, is much superior. The coke should be hard-burned, with strong, firm structure to bear up the burden and not crush. In composition, sulphur is the most injurious element and should be as low as possible; ash is objectionable merely as an adulterant, lowering the melting value and requiring more flux; phosphorus is of less consequence than in blast-furnace practice, as the ratio of coke to metal is so much less and it is doubtful if much or any of the phosphorus in the coke enters the iron in melting. The range in analysis of most cupola coke is given in Table I.

TABLE I
RANGE OF ANALYSIS OF COKE

	Ash Per Cent.	Fixed Carbon Per Cent.	Volatile Matter Per Cent.	Sulphur Per Cent.	Phos- phorus Per Cent.
Minimum .	8.00	87.00	.50	.75	.005
Maximum .	12.00	91.00	1.00	1.25	.015

In starting the cupola, coke for a *bed* is charged on the bottom, with enough wood to light it readily, a little distance above the wind box, or the lower tuyères; when this is thoroughly ignited, with the blast turned on, the regular charging of pig iron and the necessary coke follows. The fuel and iron ratios range from 1 pound of coke to 8 pounds of iron up to 1 pound of coke to 15 pounds of iron, good practice being about 12 pounds of iron melted with 1 pound of coke.

21. Flux.—The flux used to form a slag with the sand on the pigs, the coke ash, and wear of lining, is limestone. The slag contains varying amounts of iron, usually from 10 to 12 per cent., and is mainly a silicate of iron and calcium. The usual range of composition of stone and slag is given in Table II.

22. Cupola Mix.—By this is meant the proportion in which the different irons together with the fuel and flux are charged to give the required composition. The silicon and sulphur are the only two elements usually figured on, as all the iron

TABLE II
RANGE OF COMPOSITION OF STONE AND SLAG

	Silica Per Cent.	Lime Per Cent.	Oxides of Alumina Per Cent.	MgO Per Cent.	Iron Per Cent.
Limestone.	1 to 5	48 to 53	.5 to 2.5	1 to 5	
Cupola slag	45 to 55	15 to 20	15.0 to 20.0	1 to 4	8 to 15

for the Bessemer process is very close to the same percentage in phosphorus and does not vary widely in manganese. The usual range of composition of Bessemer pig iron is given in Table III.

Carbon is not considered in the calculation. With the phosphorus below the Bessemer limit of .1 per cent., the sulphur

TABLE III
RANGE OF COMPOSITION OF BESSEMER PIG IRON

	Silicon Per Cent.	Sulphur Per Cent.	Phos- phorus Per Cent.	Man- ganese Per Cent.	Carbon Per Cent.
Minimum.	.75	.02	.08	.4	3.75
Maximum.	2.00	.06	.10	.8	4.25

not exceeding .05 per cent., and manganese about .6 per cent., silicon is the chief element controlling the mix, though the sulphur and phosphorus are not less important; in fact, even more so, as the process has no control over these, while the silicon may vary within considerable limits without serious disadvantage to the product. The silicon is the principal fuel in the process and is necessary for this reason. Formerly

2 to 2.5 per cent. was considered necessary in the pig iron for successful working, but in present practice about half of this is used. This is due to more rapid working and to using less steel scrap in the cupola and vessel.

23. In melting, there is a gain of sulphur, by absorption from that in the coke, so that the metal tapped out contains from .02 to .035 per cent. more sulphur than did the initial pig iron; the increase depends mainly on the amount in the coke, but somewhat on melting conditions and on the lime charged. There is a loss of silicon in the cupola, as some is oxidized and enters the slag, the amount depending somewhat on the initial silicon in the pig and the melting conditions—the blast and rapidity of melting. Under similar conditions, the loss of silicon is greater the higher the silicon is in the pig; it is usually taken as .2 to .3 per cent.

24. Operating a Cupola.—The metallurgist who wants to advance in his profession must take a broader view of the subject of cupola operation than is customary in many plants and foundries, where the cupola is run by rule of thumb, and often an awkward thumb at that. In a Bessemer plant, where the cupola runs continuously for three to six days, and the coke ratio must be small and the output large, the scientific management to which cupolas are amenable should be applied. The orthodox foundryman's idea of throwing a little more fuel into the cupola when it does not seem to be working just right may be the very act to put the cupola out of business, besides making the iron cold for as long as the heat continues. Cupola operation is like that of the blast furnace, and deserves its share of the attention of the plant management, instead of being relegated to an unscientific foreman.

25. Cupola Zones.—Like the blast furnace, the coke bed of the cupola extends from the bottom to the melting zone, which is a narrow zone of 6 inches or so in width, beginning 15 to 24 inches above the top of the tuyères, depending on the diameter of the cupola, the pressure of blast, and the volume of blast as related to the diameter. In the melting

zone, all the iron, scrap, flux, etc. are reduced to liquid form, and nothing remains solid below that point except the bed of coke which supports the charge, and which, in turn, rests upon the cupola bottom. Even when liquid iron forms a reservoir in the crucible—that is, the zone below the tuyères—the coke bed also extends through this crucible and rests upon the cupola bottom. This statement is the subject of much plant discussion, and it may be well for those of an inquiring mind, to insert an iron rod through the tap hole and satisfy themselves that the coke is really there. The point is important, because another depends upon it, and this second point is also one which is debated hotly by *practical* cupola men, namely, that iron allowed to collect within the cupola crucible and drawn off at intervals when a large “tap” has accumulated, is colder than the same iron drawn off continuously and collected in a ladle. Many demonstrations have proved beyond doubt that the statement in the previous sentence is true, but the young metallurgist must debate it with caution, lest he lose his reputation and good will among the “practical” men of the plant. The practical men are the most important men for the operation of the plant.

Above the melting zone is the cupola stack, which should have, for best fuel economy, at least three or four times the height of the diameter of the cupola. The stack ends at the level of the charging door.

26. Cupola Melting.—The cold blast should be driven into the cupola at a pressure not exceeding 8 ounces per square inch for small cupolas and 14 ounces for large ones. It unites with the coke opposite, and immediately above, the tuyères and creates intensely hot gases, which rush up the stack, melting everything in the melting zone and then giving up their surplus heat to the descending iron, flux, and coke, thus preparing them for the period of combustion. Successful melting, hot iron, and fuel economy depend upon the following conditions:

1. The melting zone must be invariable; it must not be too high above, nor too near, the tuyère zone. Either con-

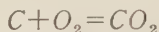
dition means cool iron and oxidized iron. To insure this condition, the blast must not be too high in pressure, or too low, and, especially, it must not be varied and tampered with. The blast volume is also important, and a gauge for measuring this is an aid to correct cupola management. Gauges that are not kept in correct adjustment should be studiously avoided.

2. The charging must be uniform; the practice of measuring the coke by forks-full, which may weigh anywhere from 18 to 35 pounds each, depending on the man who is doing the forking, or the state of mind or temper of the foreman, who may call for piling up the forks a little fuller, is one of the most fruitful sources of cold iron. Weighing the coke, or a good gauge for measuring it uniformly, and an equally definite means of assuring a uniform charging of iron, are great helps in getting hot metal and fuel economy, as well as sulphur purity.

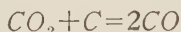
3. The stack must be kept full. On hot days, when the foreman is not watchful, the charging men find it easier to pile the stack up with stock and then go away and rest until it has sunk down to a low level. This gives variable pressure of blast and insufficient absorption of heat by the descending stock. Its most serious consequence is lack of uniformity in cupola operation, and, especially, variation in the position of the melting zone.

4. The cone of carbon monoxide must be reduced to a minimum. The blast is driven inwards and upwards. This makes unavoidable a cone in the center of the cupola, near the tuyère level, where there is incomplete penetration, and this means cold iron, because all the metal that is melted in, or drops through, this CO cone is colder than the metal which has been exposed to the CO_2 areas. Only when the CO cone is small in size is the amount of metal which is exposed to it in so great a minority as not to affect seriously the temperature of the general product. The blast penetration and combustion must be regulated so as to keep down the CO cone and still maintain the melting zone at a uniform level above the tuyères.

This CO cone is so important that a few words as to its origin are worthy of attention: When the oxygen of the blast strikes the coke the immediate reaction is



This reaction produces the highest temperature of which the combustion of coke is capable. But when the CO_2 comes in contact with more red-hot coke, a further reaction takes place:



This reaction, which takes place with insufficient free oxygen absorbs much heat, and actually robs the gases of their temperature. Therefore, in those areas where gases contain CO instead of CO_2 , the temperature will be low. The theory of the melting zone is that it forms the upper level of the zone of CO_2 combustion; in other words, the iron gets, between the melting zone and the tuyères, the highest temperature which the cupola is capable of giving it. The CO cone is a cone of low temperature within this region.

5. The melting zone, besides being invariable, must be situated the correct distance above the tuyères. The careful melter, before the cupola is patched up after a heat, goes inside and observes the position of the melting zone. It is indicated by the annular ring in which the cupola lining is deeply cut. If this ring is more than 6 to 9 inches wide, it shows that the melting zone has been moving up and down. From the position of the ring after good or bad melting the melter can soon learn what is the best position for hot melting. The volume of the blast controls the position of the melting zone; as blast volume is seldom measured in cupola practice, the pressure of the blast is understood to control the melting zone, but this is an irregular and uncertain indication.

6. The iron-oxidizing area must not be excessive. The melted iron is subject to oxidation by the blast. Some such oxidation is inevitable, but may be corrected, in part at least, by the incandescent coke with which the metal comes in contact thereafter. Oxidized iron makes skulls in the ladles, because it chills at a temperature at which unoxidized iron will be

fluid. Too high blast volume causes excessive iron-oxidizing areas in the cupola. Good practice requires about 27,000 cubic feet of blast for each ton of iron melted. If say, 20 tons of iron is to be melted per hour (one-third of a ton per minute) then it must be planned to use about 9,000 cubic feet of blast per minute, and a blower should be provided capable of about 25 per cent. excess capacity.

27. Coke Charges.—Obviously there must be charged into the cupola every 10 minutes, or so, as much coke as is burnt at the tuyères in the same time. The question then is how large should each coke charge be, and what should be its weight or its volume. The volume of each coke charge should be such as to fill the cupola in a level layer about 9 inches deep. The best way to find out what this volume is, is to make the actual test when the cupola is empty. Each coke charge should be about one-tenth to one-twelfth of the weight of the iron charge.

28. Iron Charges.—Each iron charge should fill the cupola in a level layer about 6 inches deep, and should melt in not more than 5 minutes. Thus, one charge will just occupy the limits of the melting zone of the cupola. Also, if 20 tons of iron is being melted per hour, each iron charge will weigh $20 \div 12$ (5 minutes is one-twelfth of an hour) = 1.67 tons = 3,340 pounds. Then, each coke charge must weigh from 280 to 334 pounds, depending on the skill, attention, and regularity given by the head operator.

29. Distribution of Charge.—The blast naturally seeks to rise in the cupola along the lines of least resistance; therefore it tends to creep up along the lining. This means poor penetration and extension of the iron-oxidizing area. This, in turn, means cold iron, excessive burning of silicon from the iron, and excessive absorption of sulphur by the iron. To correct the tendency, a goodly share of the small scrap, especially steel scrap, should be charged along the cupola sides, and those materials which, by their shape or size, tend to make the stock readily permeable to the blast, should be charged in the center. Care and attention to this important

point will accomplish an even distribution of the blast and rising gases.

30. Spiegel Cupolas.—The burdening of the cupolas in which the recarbonizing additions are melted, is under the direction of the Bessemer plant metallurgist. The object is to melt a mixture of pig iron, spiegeleisen, ferrosilicon, etc. to produce a melted metal for recarbonizing. This recarbonizer, when added to the steel from the converter, will give to it just the desired percentage of carbon, manganese, and silicon. The calculation is complicated, but not difficult. The weight of the steel, and what percentage of carbon, manganese and silicon is desired in it must be known; then it must also be known what percentage is lost during the recarbonizing reactions (in this connection reference and study should be given to the whole question of recarbonizing, which is discussed in detail under the head of Acid Open-Hearth Steel); again, it must also be known what percentage of manganese and silicon are burned out in the spiegel cupola. Each plant has its own rule for making these calculations, but the man who is to go upwards is the man who understands the principles upon which such rules are formulated.

31. Carbon Calculation.—The carbon calculation is the simplest, because the product of the spiegel cupola contains about 5 per cent. of carbon under all circumstances. The method of calculation is as follows: Assume that the converted metal weighs 30,000 pounds and contains .04 per cent. of carbon; that rail steel is to be made and is to contain .60 per cent. of carbon, and that 80 per cent. of the carbon added will dissolve in the steel.

Then, the amount of carbon to be added is the per cent. desired minus the per cent. already present, or

$$.60 - .04 = .56 \text{ per cent.}$$

The amount of carbon to be dissolved by the steel is

$$30,000 \times .0056 = 168 \text{ pounds}$$

The amount of carbon to be added in order that 168 pounds will be dissolved is

$$168 \div .80 = 210 \text{ pounds}$$

The amount of spiegel to be used is the amount of carbon divided by the carbon content of the spiegel (5 per cent.), or

$$210 \div .05 = 4,200 \text{ pounds}$$

32. Manganese Calculation.—The manganese calculation is made on the assumption that the conditions are the same as given in the preceding calculation and also that 80 per cent. of the manganese in the melted mixture remains in the steel after the recarbonizing reactions; that 90 per cent. of the manganese charged into the cupola goes into the melted recarbonizer, and that 1 per cent. of manganese is desired in the steel.

Then, the amount of manganese desired in the final steel is

$$30,000 \times .01 = 300 \text{ pounds}$$

The amount of manganese to be added with the recarbonizer is

$$300 \div .80 = 375 \text{ pounds}$$

The amount of melted spiegel mixture to be used is 4,200 pounds, as shown in the carbon calculation. Therefore, the per cent. of manganese in the melted spiegel mixture is

$$375 \div 4,200 = 8.9 \text{ per cent.}$$

and the per cent. of manganese in the spiegel cupola charge is

$$8.9 \div .90 = 9.9 \text{ per cent.}$$

33. Silicon Calculation.—The silicon calculation is made on the assumption that the conditions are the same as in the two preceding calculations, and also on the further assumption that .25 per cent. of silicon is dropped in the cupola; that .15 per cent. of silicon is wanted in the final steel after the recarbonizing reactions are completed; and that 70 per cent. of the silicon added with the recarbonizer is found in the finished steel.

Then, the amount of silicon desired in the finished steel is

$$30,000 \times .0015 = 45 \text{ pounds}$$

The amount of silicon that must be added to the melted spiegel mixture is

$$45 \div .70 = 64 \text{ pounds}$$

Then, the per cent. of silicon that must be in the melted spiegel mixture is

$$64 \div 4,200 = 1.52 \text{ per cent.}$$

and the per cent. of silicon which must be in the spiegel cupola, including the .25 per cent. dropped in the cupola, is

$$1.52 + .25 = 1.77 \text{ per cent.}$$

34. Spiegel Cupola Charge.—The preceding calculations show that the spiegel cupola must be charged with a mixture containing 1.77 per cent. silicon and 9.9 per cent. manganese. From the pig yards, pig iron and spiegel, and ferro-silicon, if necessary, are selected and the charge made up accordingly. Then 4,200 pounds of this charge are run out after melting, and added to the Bessemer metal.

35. Checking the Calculations.—Every calculation should be checked back, because a mistake in the spiegel mixture may involve thousands of dollars' loss to the steel mill.

36. Mixer.—Fig. 2 shows a section through the mixer. This is a reservoir for storing the molten metal from the blast furnaces, and has come into general use. The construction is simple, it being merely a strongly framed structure of steel plates lined with firebrick. Two or four hydraulic cylinders *c* are placed at each corner, or one side, for tipping it to pour out the metal. It is provided with a hopper, or funnel, *a* at the back, as shown, or in the center of the roof. The pig iron is run into ladles at the blast furnace and transferred by a locomotive to the mixer; or if the blast furnaces and steel plant are close together, a traveling crane is generally provided for transporting the ladle and pouring into the mixer. In the former arrangement the ladle is run up an elevated track, raised by a hydraulic lift or a crane to a sufficient height above the mixer to pour it readily.

The advantages in using the mixer are that remelting the pig in cupolas is avoided, thus saving the expense of fuel and handling; and that the loss is less. Molten metal has been taken direct from the blast furnaces to the converters, but the results have not been satisfactory, owing mainly to

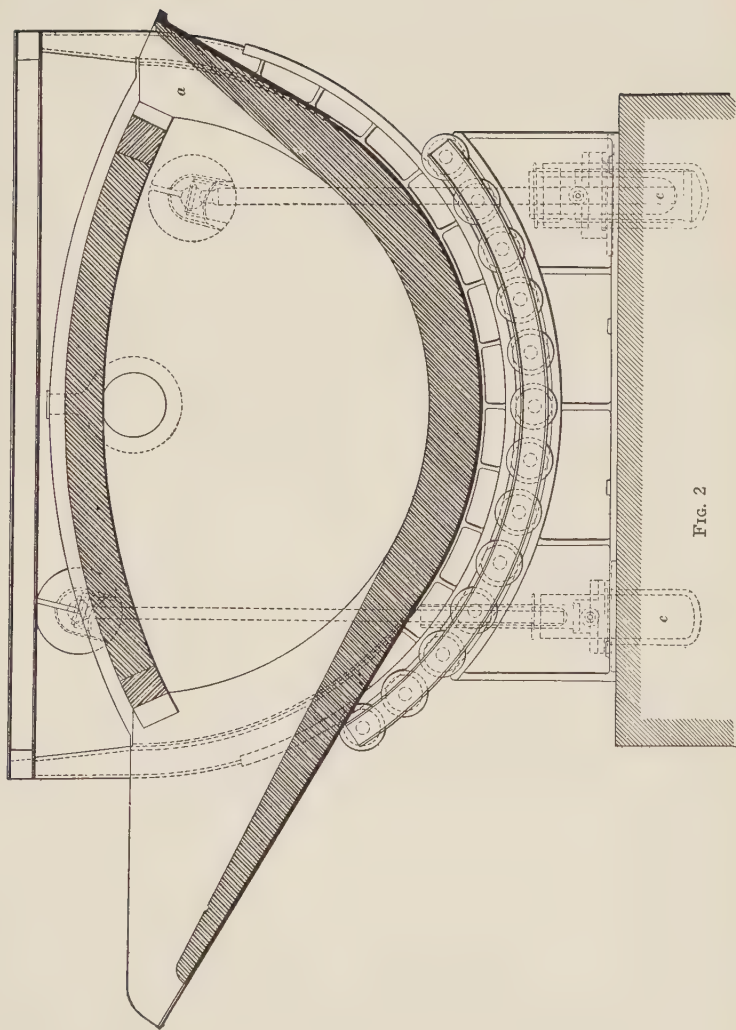


FIG. 2

the varying composition from one cast to another and also to the fact that the metal was not available just as wanted, or came in too large quantities when entire casts came at once. The mixer furnishes the metal exactly as it is wanted; and, what is even more important, it supplies a more uniform metal from the mixing of a number of casts. These mixers are made to hold from 150 to 250 tons and are of service where blast-furnace and Bessemer plants are operated together and there is a large output from both; generally the metal is transported only short distances, but it has been successfully taken in ladles from 2 to 3 miles.

Cupolas are usually operated in connection with the mixers to supply part of the metal for blowing when the blast-furnace output is below the converting capacity. It is also usual to employ the cupola as a corrective of the mixer. For example, on a cold, dry day the iron may be coming too high in silicon; then a cupola mixture is used which is enough lower than the amount desired to adjust the analysis to the desired point.

37. Sulphur in the Mixer.—There is a slight loss of sulphur from the metal in the mixer, due to a slow segregation of manganese sulphide to the surface of the metal bath, where the sulphur becomes oxidized and transformed to SO_2 which escapes in the gases.

38. Converter.—This is the essential apparatus of the process and the one in which the pneumatic principle is applied. It is an oval vessel with a symmetrical nose, as shown in section in Fig. 3, or an eccentric nose, as in Fig. 4. The former is more generally used now, although at one time the latter was used almost exclusively. It is made of heavy riveted plate steel and is lined with refractory material—ganister for the acid, and dolomite or magnesite for the basic process, as in the open-hearth. It is suspended about the middle on trunnions, shown at d and d' , Fig. 3, one of which, d' , is hollow, and through which the blast passes from the blast pipe by way of the gooseneck e to the vessel's bottom and thence through the tuyères to the metal. The vessel is rotated by hydraulic power

applied through a rack and pinion. The construction is such that it can be made to revolve completely and empty out any slag after pouring the steel. Referring to Fig. 3, it will be seen that the vessel consists of three principal sections keyed together to form the complete converter. The middle, or main section *b*, around which the trunnion ring *a* extends, holds the

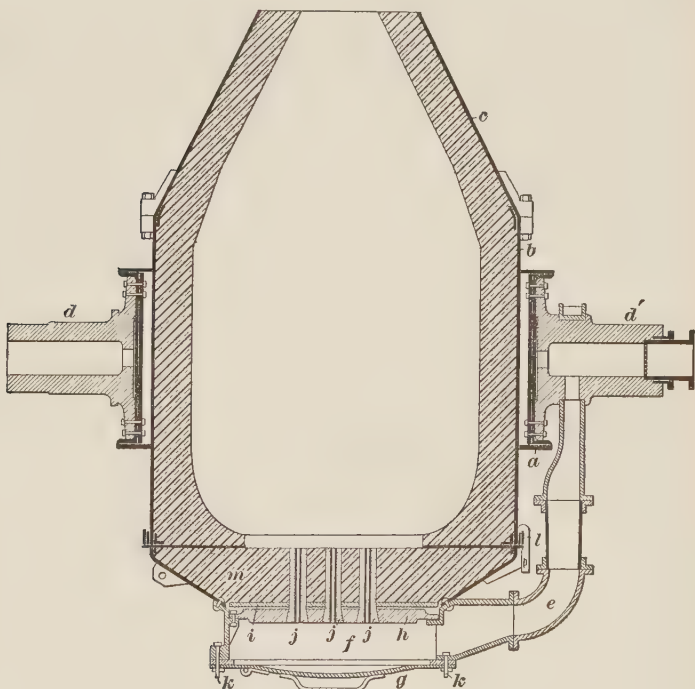


FIG. 3

body of metal while it is being blown. The bottom *m* is detachable and is held to the body of the vessel by keys and links *l*.

Originally, the bottom was not movable, but the latter construction (an invention of Holley's) did much to facilitate repairs and speed of working. Beneath the bottom proper is the tuyère box *f*; its cover is keyed on at *k* and is air-tight; the nose of the converter *c* is also keyed on to the main part,

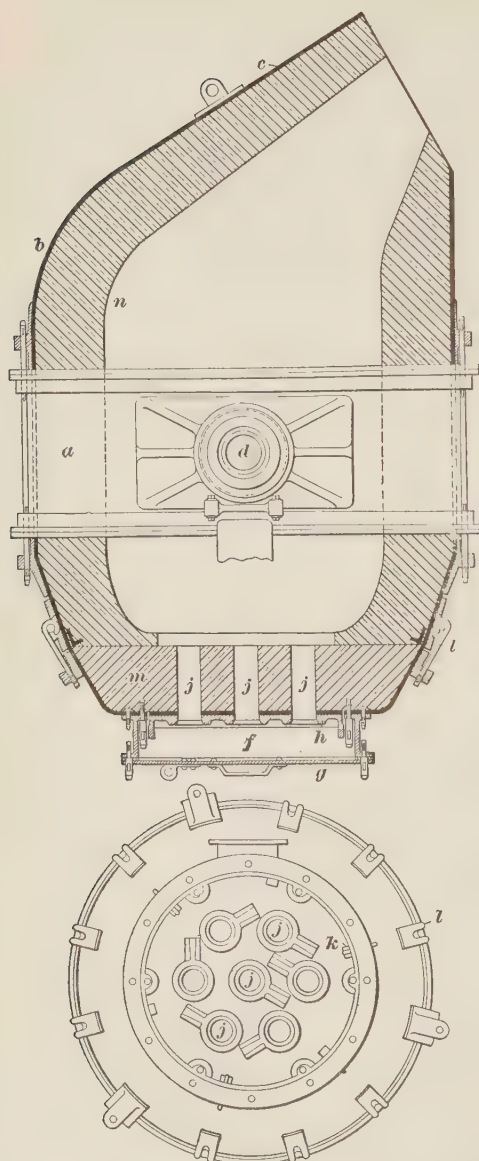


FIG. 4

permitting its removal for repairs, etc. The straight- or concentric-nosed vessels are generally held to slop less than the eccentric-nosed ones; that is, less metal is thrown out of the converters by the violence of the reaction. They are made in sizes of 1 to 20 tons capacity, but blow about 5 tons in small plants and from 10 to 20 tons in the large plants. Those having a capacity of less than 5 tons are usually found in steel-casting plants where the output is limited. The metal fills only a small part of the space in the converters, as the reaction is so violent that abundant room must be allowed for it. When the vessel is turned down at the end of the blow, the metal lies in the belly, which is shown at *n*, Fig. 4, so that it will be clear of the tuyères and not run out the nose.

THE ACID BESSEMER PROCESS

39. Introductory.—The acid and basic Bessemer processes bear the same relation to each other as to the acid and basic open-hearth processes. The lining for the converter in the acid process being of acid material, dephosphorization and desulphurization do not take place, owing to the acid slag necessary; hence the process is limited to comparatively fine pig irons, as in the acid open-hearth process.

40. Bottom and Tuyères of Converter.—The bottom for the acid process is made up of ganister rock. Its thickness is 26 to 30 inches. The tuyères *j* are spaced over the bottom and supported from below by the tuyère plate *h*, Figs. 3 and 4; they are placed in position before the bottom is built up and the ganister built up around them. Their length corresponds to the thickness of the bottom (26 to 30 inches), so that their inner face comes flush with the latter. They are cylindrical in shape, about 6 inches in diameter, and contain from 6 to 10 holes $\frac{3}{8}$ to $\frac{1}{2}$ inch in diameter; their number varies from 7 to 12 and the total tuyère area (that is, the area of the holes) varies from $2\frac{1}{2}$ to 4 square inches per ton of metal blown. After being made up, the bottoms are run into drying ovens and thoroughly burned. Their life varies from a single heat occasionally, to 50 or 60 rarely; 30 to 35 heats for a single bottom may be taken as good average practice. The tuyères are made of hard-burned and very refractory fireclay; in blowing, it frequently happens that a tuyère will be cut through by the metal—when the vessel is turned down, the lid *g* of the tuyère box removed, and a circular plate inserted over the tuyère or blanked; the heat can be blown with a number of the tuyères blanked, but the blowing time is increased. Bottoms are changed in some works by turning the vessel into a vertical position with the nose down, and after unkeying, a crane lifts it off and places a fresh one in position. In others, the vessel is turned with the bottom down and a car is run under it on which the bottom is dropped, a hydraulic lift raising the car against the bottom; a fresh bottom on another car is

raised against the vessel and keyed on. The latter is the more rapid method.

41. Lining and Repairing.—The lining is about 12 inches thick, and is made up of ganister or silica brick, usually the former, ground with about a fifth part of refractory clay. The vessel's lining lasts much longer than the bottom, as the latter is supporting the charge most of the time and the cutting action is more intense on it. But the chief reason is that FeO is formed just at the tuyères, and its corrosive effect is great. It is usually reduced by the metalloids or absorbed by the slag before it reaches the side lining. From 3 to 5 months is an average life for a lining, or 5,000 to 10,000 heats. Repairs are required constantly, especially around the nose, which is injured by *spittings* and by pouring the steel. After a vessel has been lined up or patched for the beginning of a week, it must be thoroughly dried out and made hot before metal may be poured in.

42. Blast.—This is furnished by vertical or horizontal blowing engines, generally the former, as they are more compact. A pressure of 20 to 30 pounds per square inch is maintained in the blast pipe, as shown by a gauge on the pulpit. The pressure is varied according to the metal to be blown and the conditions of the vessel—depending on the bottom, number of tuyères blanked, etc. The blow lasts from 7 to 12 minutes, but with very large heats or a deficient blowing capacity it may exceed the latter.

43. Chemical Changes in the Converter.—In general, the elements are oxidized in the same order as in the open-hearth process. In the acid Bessemer process silicon is burned to SiO_2 , manganese to MnO , and simultaneously with this, some iron is oxidized, forming the slag with the SiO_2 and MnO . The silicon and manganese go largely together. The carbon is next oxidized. With ordinary pig iron, the silicon and manganese will be reduced to little more than traces before much carbon is burned, but with excessively high manganese the carbon will be largely burned before the manganese is gone.

Table IV shows the progressive removal of the elements in blowing.

44. This is the practice of a normal heat in American plants, but the removal of the metalloids is dependent on what is called the *critical temperature* of the Bessemer process. To understand this it must be recalled that increasing temperature brings with it a greater increase in the affinity of carbon

TABLE IV
PROGRESSIVE REMOVAL OF ELEMENTS IN BLOWING

Element	Initial Pig Iron	Time After Beginning to Blow				
		2 Minutes	3 Min. 20 Sec.	6 Min. 3 Sec.	8 Min. 8 Sec.	9 Min. 10 Sec.
Carbon....	2.98%	2.940%	2.710%	1.720%	.530%	.040%
Silicon....	.94%	.630%	.330%	.030%	.030%	.020%
Manganese	.43%	.090%	.040%	.030%	.010%	.010%
Phosphorus	.10%	.104%	.106%	.106%	.107%	.108%
Sulphur...	.06%	.060%	.060%	.060%	.060%	.060%
Character of Flame From Converter		Silicon Flame	Brighten- ing (Carbon Starting)	Moderate Carbon Flame	Full Carbon Flame	Flame Drops

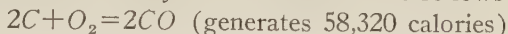
for oxygen than that of all the other elements. Thus, as has already been seen, phosphorus is oxidized rapidly in the basic open-hearth process if the temperature is low; but, if it is high, carbon is burned off rapidly and phosphorus may not be burned at all. It is the same with silicon and manganese. When the temperature of the Bessemer process is low—as at the beginning of the heat, for example—silicon and manganese are eliminated first; but if, at any moment, the oxidation of these metalloids raises the temperature beyond that critical point at which the affinity of carbon for oxygen exceeds the affinity of the other elements, then carbon begins to burn rapidly and only traces of the other elements are oxidized thereafter, until the carbon is all gone. Therefore, in English Bessemer practice,

where it is common to start the *blow* with silicon of 2 or even 2.50 per cent., it often happens that the silicon will not all be burned when carbon begins to go, and what is known as *residual silicon* exists at the end of the blow. Likewise, in Swedish practice, where high manganese is put in the iron used for blowing, residual manganese is common at the end of the operation.

45. A study of the table shows that the carbon burns very little until the silicon and manganese are practically gone. The beginning of the carbon to burn is called the *breaking through* of the flame, and when it is all burned, *the drop of the flame*. The latter point is sharp and marked so that an experienced eye can catch the point where the flame drops. While a slight increase in phosphorus is shown, it amounts only to the gain from concentration, that is, the actual weight of phosphorus is the same in the blown metal as in the pig iron, whereas the weight of the blown metal is considerably less (about 8 per cent.) than that of the pig iron; this applies to sulphur also and there is usually a gain of both phosphorus and sulphur corresponding to the loss in blowing. This loss will depend mainly on the percentages of carbon, silicon, and manganese in the iron; the loss is not only the actual amount of these, but iron is always oxidized; an increase of silicon calls for an increased amount of iron in the slag, as the silicon in forming the double silicate of iron and manganese takes up more iron, unless an unusual amount of manganese is present, as ferrous oxide FeO and manganous oxide MnO can replace each other to a large extent. The combined percentages of these two oxides in the slag amount to 30 or 35 per cent. in most cases, together with 60 to 65 per cent. of SiO_2 .

46. Temperature in the Converter.—Silicon is the great heat producer in the acid Bessemer process. The oxidation of carbon and manganese produces considerable heat—large quantities in fact—but not enough for the reaction, as is clearly shown by the fact that a decided decrease in the percentage of silicon causes the metal to blow cold.

The heat evolved by the metalloids is as follows:



But it is noted that the heat generated by the silicon and manganese is all retained in the converter when these compounds dissolve in the slag. On the other hand, the heat generated by the carbon is partly carried away when the CO gas escapes from the metal and pours out of the mouth of the vessel in a brilliant flame; therefore, it is the heat from combustion of silicon and manganese which does most to increase the temperature of the bath.

Formerly 2 and even 3 per cent. of silicon was considered necessary to furnish the requisite heat, but this amount has been reduced to such an extent that the average metal going into the converter to be blown contains .9 to 1 per cent. This decrease has been due mainly to a discontinuance of the use of scrap and to more rapid work throughout the process. The decrease is also very economical, as the loss is decreased not only by the lessened silicon, but by more than an equal amount of iron taken up by the slag.

47. Loss in the Acid-Bessemer Process.—The three chief sources of Bessemer loss are: oxidation of metalloids; iron absorbed in the slag; and spitting of metal from the mouth. The average amount of slag is 7 per cent. of the weight of the metal, and it contains about 15 per cent. of iron in the form of FeO . Then the approximate losses will be as follows:

	PER CENT.
Loss of iron is 7 per cent. of slag times 15 per cent. of Fe in the slag.....	1.05
Loss of carbon burned.....	4.00
Loss of silicon burned.....	1.00
Loss of manganese burned.....	.50
Loss by spitting.....	1.50
Total normal vessel loss.....	8.05

The acid-Bessemer slag contains about 65 per cent. of silica; therefore, everything which increases the amount of the silica

present will increase the amount of slag, and, consequently, the amount of iron lost therein. High silicon in the metal, or a badly made bottom which wears badly and dissolves in the slag, or a very hot blow, which increases the corrosion of the lining, are all causes of excessive silica. This result, as well as excessive spitting, and careless teeming, and the production of ingot butts, instead of whole ingots, are the three chief causes of lowered production from a given amount of pig iron charged to the converters.

48. Cooling the Temperature of a Too-Hot Bessemer Bath.—It was learned that too high a temperature increases the loss. It also lowers the quality of the steel; first, because steel which is teemed too hot is subject to the evils of segregation and coarse crystallization, which, in some phases is known as *ingotism*, etc.; and, second because a uniform temperature of teeming the metal into the molds is essential to a proper control of the formation of blowholes. The customary manner of cooling the blow is to admit live steam into the entering blast of air. The chemical decomposition of the steam absorbs heat as follows:



This method of cooling is better under present conditions than the practice of throwing into the vessels, during the blow, amounts of steel scrap estimated by the blower, because scrap is now needed for open-hearth furnace stock, and because the use of scrap involves more labor.

49. Increasing the Temperature of a Cool Bath. In the case of cold heats, side blowing is resorted to—the vessel is turned down approaching a horizontal position, until some of the tuyères are exposed above the surface of the bath, and as the air is blown over its surface, iron is oxidized, the oxidation producing heat. It is an expensive way to increase the temperature, but occasionally it is the only way, as heats are sometimes unavoidably too low in silicon, or else they blow cold from other causes, such as low temperature of the metal from mixer or cupola, cold converter, etc. In addition

to burning iron to produce heat, side-blowing also burns the carbon more completely:



The normal reaction in blowing is:

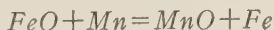


If, therefore, the CO be further oxidized by "side blowing," the carbon combustion produces more than twice as much additional heat. It should be noted, however, that this additional heat is developed above the bath, instead of within it, as is the case with oxidation to CO , FeO , MnO , SiO_2 , etc.

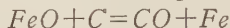
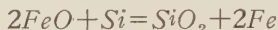
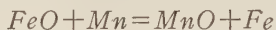
Another costly way of increasing temperature is to add some ferrosilicon during the boil. Silicon would not burn while carbon was being oxidized if the temperature were above the critical temperature, which has been discussed, but, during a cool blow, the added silicon burns along with the carbon and increases the temperature very satisfactorily.

50. Recarbonizing.—Recarbonizing for low-carbon steels is done in the ladle by the addition of ferromanganese: for high carbon and medium carbon steels, by using melted spiegeleisen or pig iron, the recarbonizer is frequently poured into the vessel. The amounts necessary to furnish certain percentages in the steel are given under the heading Spiegel Cupola, together with the loss, etc. Vessel recarbonizing is better than ladle recarbonizing because it gives a much better mixing of bath and recarbonizer; it also gives more opportunity for the metalloids in the recarbonizer to yield. This is especially true of the stirring of the two during the pouring from vessel to ladle. Finally, vessel recarbonizing permits a longer time for the recarbonizing reaction to take place, and this is more important than is customarily appreciated.

51. Recarbonizing Reactions.—In relation to recarbonizing reference should be had to the whole subject as discussed in a preceding Section. In its special reference to acid Bessemer, there is a decrease in the iron contained in the slag and an increase in the manganese, due to the following reaction:



There is also a slight increase in the volume of the slag, because of oxidation of metalloids with consequent reduction of FeO dissolved in the metal



52. Holding the Slag Back in the Vessel.—If the slag is held back in the vessel while pouring the steel into the ladle, it helps to oxidize the metalloids during the first part of the next succeeding blow, and also gives the bath some of its iron.

Some operators have even increased the yield of the process by adding iron ore (or mill scale) to the bath before the blow begins. The time of blow is as much as 20 per cent. less when the slag is held back. High manganese in the pig iron blown, by making wet and sloppy slags, increases the difficulty of holding the slags back.

53. Casting, Etc.—Casting is common to both the Bessemer and open-hearth processes, and is accomplished in about the same manner. The older practice, and one that was universal until within the past 30 years, was to have a circular or a semicircular pit, with the steel crane in the center and the molds placed around its circumference, so that the crane could reach any part of the pit. The molds and heats were made to correspond, so that a heat would give an even number of ingots and avoid butts, which are either inconvenient to handle or must be remelted as scrap. Just as in the open-hearth process, or more correctly it was first done in the Bessemer process, practically all plants cast the ingots in molds carried on cars, two or three to each car. This method avoids a pit, always a dirty part of the plant; but economy is the controlling motive in such matters. The molds are pushed to the stripper, usually in a separate building, and removed from the ingots, the latter being left standing on the cars and the molds removed and placed on other cars, or the mold and the ingot are both removed and the ingots pushed out on cars to be taken to the heating furnaces—the *soaking pit* or *pit furnace*.

54. Tropenas Process.—The Tropenas process is adapted to making steel castings and is carried out in a special Bessemer vessel in which the blast of air is blown on top of the metal instead of through it. From very early in its history, top-blown or side-blown converters have been used at different times in the development of the Bessemer process.

The Tropenas process is shown in Fig. 5 (a) in vertical section, while Fig. 5 (b) is a horizontal section through the lower wind box *e*. It has an upper and lower wind box *e* and *f* on one side of the vessel, from each of which horizontal tuyères extend through the side of the vessel. They are of large diameter, from $1\frac{1}{4}$ to 2 inches, and so placed that the ends are always above the bath. The upper row of tuyères *d* are placed from 4 to 7 inches above the lower *c* and are not used until the metal is desiliconized by the lower row and the carbon flame starts, when air is admitted to the upper wind box to burn the carbon monoxide formed from the oxidation of the carbon. The purpose of this is to utilize the heat of the carbon monoxide, which is largely added to the bath by radiation.

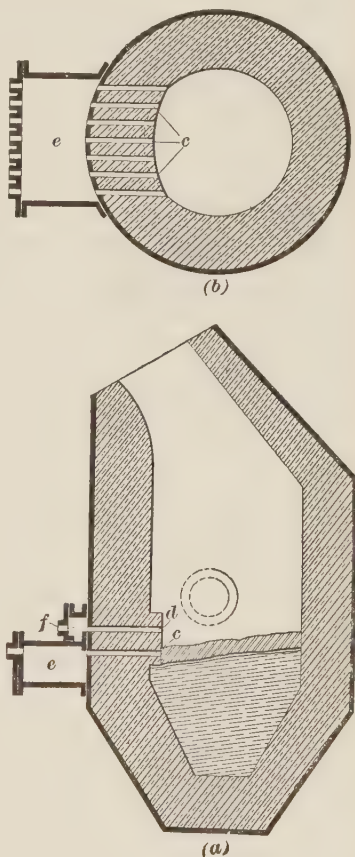


FIG. 5

55. This is merely taking advantage of what was described as *side blowing for heat* in the acid Bessemer process; namely,

the carbon is burned to CO_2 instead of to CO , thus generating much more heat. The blowing is stopped, as in the ordinary converter, when the carbon flame disappears; the recarbonization is made in the converter and the metal poured into a ladle for casting. It is claimed that a much hotter metal is obtained than by the usual practice, that more delicate and intricate shapes can be cast from it, and that the quality of the metal is improved. The vessels are of 1 or 2 tons capacity. The advantages are the cheaper installation than an open-hearth, as the converter may be placed in any foundry with a cupola to melt the pig iron. The pig metal used is from 1.75 to 3 per cent. silicon, .04 to .1 per cent. phosphorus, .03 to .06 per cent. sulphur, .5 to 1.25 per cent. manganese, and 3.5 to 4.25 per cent. carbon; it is the high silicon and the super-oxidation of carbon that gives the excessive temperature which permits pouring of difficult castings. Owing to the high silicon, the loss in blowing is excessive, reaching from 10 to 12.5 per cent. The metal is recarbonized to the same composition as ordinary castings. A low blast pressure (3 or 4 pounds per square inch) is used.

THE BASIC BESSEMER PROCESS

56. Introductory.—The basic Bessemer process bears the same relation to the acid Bessemer process as the basic open-hearth process does to the acid open-hearth. Conversion is accomplished in the same way as in the acid Bessemer process—by blowing air through the molten iron—with the essential difference that purification is effected by introducing a lime charge; the basic slag resulting requires the use of a basic-lined vessel. It renders available for steel making irons entirely too high in phosphorus for the acid Bessemer process and also too high for economical use in the ordinary basic open-hearth process.

57. The principle of the basic process was first applied to the Bessemer and afterwards to the open-hearth process, the latter being now much the more important of the two basic processes. Germany has made the greatest development

of the basic Bessemer process, mainly owing to available pig irons better adapted to it than to the basic open-hearth process. Two plants were started in America, but neither is now in operation.

58. Pig Iron Used.—The essentials in pig iron are a low-silicon and high-phosphorus content. It was at first thought that moderate percentages of the latter (under 1 per cent.) could be used to advantage, but later practice demonstrated the necessity for 2 or 3 per cent. of phosphorus for the best results, as the oxidation of this element furnishes the bulk of the heat, instead of the silicon, as in the acid Bessemer process. Silicon could be almost, if not entirely, dispensed with, but it is impossible to make pig iron otherwise suitable (low enough sulphur) without considerable silicon. It should be below .5 per cent. and should in no case exceed 1 per cent., the latter being too high for an average mixture. The chief reason why low silicon is imperative is on account of the lime used for the basic slag required, so that the smallest amount of silicon possible must be in the charge if a sufficiently basic slag is to be produced without an excessive use of lime. Manganese ranges in the practice of different works from .75 to 3 per cent.; from 1 to 2 per cent. may be taken as the usual limits. The higher manganese is required to furnish some of the heat required at the beginning of the blow—the low silicon not giving enough heat at this stage, the manganese, being oxidized immediately after the silicon, supplies the deficiency. A further advantage is the desulphurizing tendency of manganese, as basic Bessemer pig is apt to be high in sulphur, owing to the low silicon required. Sulphur is removed to a slightly greater extent than in the basic open-hearth process, and may therefore be somewhat higher in pig metal to produce the same sulphur content in the steel. It should not exceed .05 per cent. to make very low sulphur steel, nor .1 per cent. in any case. Carbon is somewhat lower than in ordinary pig iron, usually 3 to 3.5 per cent. Owing to the low silicon, high manganese, and phosphorus (all of which promote this tendency), the carbon is mostly combined, giving the iron a

white or silvery-gray fracture. The pig iron is either melted in cupolas or taken directly from the blast furnaces, the same as in the acid Bessemer process. Table V gives the usual limits of analysis of pig irons.

59. Basic Converter—Lining and Bottom.—The converter is constructed, the same as the acid vessel, of heavy plate steel mounted on trunnions so as to be rotated. Owing to the large amount of slag and the lime charge, it is from 50 to 60 per cent. larger than the acid converter for the same iron charge. The usual capacity is from 5 to 15 tons of metal.

TABLE V
ANALYSES OF BASIC BESSEMER PIG IRONS

Works	Silicon Per Cent.	Manganese Per Cent.	Phosphorus Per Cent.	Sulphur Per Cent.
Middlesbrough, England..	1.0 to 1.3	.6 to 1.0	1.5 to 2.75	.050 to .12
Kladno, Austria.....	1.2 to 1.3	.3 to .5	1.5	.105
Witkowitz, Austria.....	.4 to .8	1.0 to 1.4	.9 to 3.40	.080 to .13
Hörde, Germany.....	.2 to 1.2	.5 to 3.0	1.2 to 2.60	.050 to .10
Creusot, France.....	1.3	1.5 to 2.0	2.5 to 3.00	.200
Pottstown, Pennsylvania..	below .5	.8	2.5 to 3.00	.020 to .05

As the converter requires more repairs than in the acid process, in order to run as continuously, three vessels are generally installed so that two may be available for use while the third is being relined. Another method, originally proposed by Holley, is to have the entire vessel removable, so that it may be taken away either by an overhead crane or on a car and a freshly lined vessel substituted, which is relined and dried in a separate shop.

The lining is built up of basic bricks, made of lime, dolomite, or magnesia, using a mortar of the same, mixed with tar. More often, the lining is rammed in of the same basic materials mixed with a little clay and about 10 per cent. of anhydrous tar to give plasticity and act as a binder for the dead-burned material. The usual thickness of the lining is from 12 to 24 inches at the bottom and from 8 to 16 inches at the nose. Con-

stant repairs are required between heats, using the lining material for this purpose.

The greatest difficulty in the early history of the basic Bessemer process was experienced in making the bottom. It is rammed up, similar to an acid bottom, of the same material as the lining—either the basic ball stuff, which is essentially a fireclay mortar, with tar, or the basic brick and this together. It is rammed in layers until a thickness of 20 to 26 inches is obtained.

60. Blowing.—The first part of the operation, or the *foreblow*, corresponds to the acid Bessemer process, when the silicon, manganese, and carbon are removed. The phosphorus is removed at a distinct stage and later, termed the *afterblow*. The blast is furnished from blowing engines, but a higher pressure (from 25 to 35 pounds per square inch) is required than in the acid process for the same size heat, depending on the size of heats, the shape of the vessel, etc. The burned lime is first introduced on the bottom, generally previously heated, or coke or coal charged with it and the blast slightly turned on to burn the latter and heat the lime charge. The latter varies from 10 to 18 per cent. of the weight of metal and depends on the amount of silicon and phosphorus in the metal, as well as on the purity of the lime. The foreblow lasts from 10 to 12 minutes, and the afterblow about 5, or the entire time of blowing averages from 15 to 18 minutes, although occasional blows last much longer, owing to variations in the charge, conditions of tuyères, or other causes. If the metal is too hot, scrap is added during the blow, the same as in the acid process, to reduce the temperature. The metal should be as hot as possible during the first part of the blow, as this prevents slopping of the charge from the converter, but the temperature should be reduced before pouring the steel so as to give a sufficiently viscid slag to avoid rephosphorization in the ladle. Too fluid or too hot a slag will allow reactions to start in the ladle and some of the phosphorus to be reduced from the slag and returned to the metal during recarbonizing.

The loss in blowing depends mainly on the character of the metal, and averages about 14 per cent. of the pig iron charged, but may vary from 11 to 19 per cent. In addition to the oxidation of the metalloids, iron is oxidized to form the slag, the same as in the basic open-hearth process, the amount depending on the percentage of silicon and manganese in the pig—higher silicon requires more iron, as well as calcium oxide, and higher manganese, less iron. Table VI shows the extent to which the metalloids are reduced and removed in the basic Bessemer converter.

61. In blowing, the conditions are judged from the character of the flame, as in the acid Bessemer process, for the foreblow, and regulated accordingly. The afterblow, during which the phosphorus is oxidized, is determined entirely by the volume of air blown through the metal, and no attention is paid to the flame or other indications, for turning down the vessel. When the change comes, that is, when the carbon flame drops (carbon being practically all oxidized), the revolutions of the blowing engines are shown by revolution counters placed in the pulpit, showing the blower the volume of air delivered. This is determined by experiment for different percentages of phosphorus, but is approximately one-half the length of the foreblow. In starting with a new mixture, when the blower judges the phosphorus to be removed, the vessel is turned down and a sample taken out with a test spoon or ladle and poured into a small mold. This is rapidly hammered out under a steam hammer, cooled quickly, and broken, a record is made of the number of blows required to break it, together with the character of the fracture indicating the degree of dephosphorization; if brittle and weak, the metal is cold short (high in phosphorus); a crystalline fracture light in color and having a general appearance soon recognized, but not easily described, shows to the experienced eye whether phosphorus is low enough, with almost the certainty of an analysis. This test having been made, the blow is continued or the steel poured as the result may indicate. After a number of blows the preliminary test is discontinued and the volume of

TABLE VI
REMOVAL OF METALLOIDS IN BASIC BESSEMER

After Beginning of Blow	Extent of Conversion	Silicon Per Cent.	Manganese Per Cent.	Carbon Per Cent.	Phosphorus, Per Cent.	Sulphur Per Cent.
Initial charge....		1.220	1.03	3.21	2.180	.080
2 min. 46 sec...	Desiliconizing or re- refining.....	.720	.71	3.30	2.150	.047
5 min. 21 sec...		.150	.50	3.12	2.220	.051
8 min. 5 sec...	Carbon flame starting.	.007	.18	2.47	2.160	.049
10 min. 45 sec...	Carbon flame full.....	.012	.16	1.49	2.100	.051
13 min. 28 sec...	Carbon flame drops...	.005	.14	.75	2.050	.051
15 min. 13 sec...	Afterblow.....	.008	.01	.05	1.910	.055
19 min. 14 sec...		.005	.01	.02	.230	.060
19 min. 31 sec...		.005		.02	.139	.055
19 min. 49 sec...		.004			.087	.056

air alone relied on for the dephosphorization, the analysis of previous heats, reported before the succeeding heat is turned down, being closely followed at the same time to check any variations in the charge or blowing. As phosphorus is the main heat producer, its percentage is regulated as the charge blows hot or cold from a variation of the other constituents—low initial temperature of the metal as it is poured into the converter, the rapidity of working, the condition of the bottom and the tuyères, or other cause.

62. Removal of Phosphorus and Sulphur.—Phosphorus is oxidized to phosphorus pentoxide P_2O_5 and combined as calcium phosphate $Ca_3(PO_4)_2$, or ferrous phosphate $Fe_3(PO_4)_2$, but almost wholly as the former, though some authorities believe the latter is present to a considerable extent. The phosphorus cannot be oxidized until the other elements are completely removed. Sulphur is removed to a considerable extent in regular basic Bessemer practice, and if the initial charge contains high manganese or if manganese is added at the close of the afterblow, much more is removed.

63. Action of the Basic Fluxes.—The functions of the basic lining—dolomite or lime—and the lime charge have already been given, the former that the necessary basic slag may be carried without destroying the vessel's lining, and the latter to produce the basic slag. The lime, of course, neutralizes the silica from the oxidation of the silicon in the pig. The percentage of silicon mainly determines the amount of lime to be used, but the phosphorus also must be taken care of by the lime charge; in practice, a considerable excess of lime is used so as to be on the safe side, as a deficiency will cause injury to or destruction of the lining as well as a failure to effect dephosphorization. It is held that the calcium phosphate can form only when the slag is saturated with bases to a lower silicate and an excess of lime is present. While phosphate of iron may be formed at first, it is gradually changed to calcium phosphate before the afterblow is completed—the iron being displaced by the stronger base. While there may be some question as to just how the different

compounds exist in the slag, it is reasonably safe to assume that iron and manganese combine as ferrous and manganous silicates, together with a part of the lime, to form an extremely basic silicate; another portion of the lime combines with the phosphorus; and the balance remains free to give additional basicity to the slag; a small amount forms calcium sulphide with part of the sulphur present.

Table VII gives analyses of typical basic Bessemer slags.

Owing to the large percentage of phosphoric acid in the slag, it becomes a valuable by-product for fertilizing purposes; it is largely used for this purpose in Europe, where large quantities of it are produced. Many methods have been proposed for preparing the slag, but it is now ground in a ball mill to extreme fineness and applied in this form.

TABLE VII
ANALYSES OF TYPICAL BASIC BESSEMER SLAGS

Number	SiO_2 Per Cent.	P_2O_5 Per Cent.	CaO Per Cent.	MgO Per Cent.	MnO Per Cent.	FeO Per Cent.	P_2O_5 Per Cent.	CaS Per Cent.
1	12.07	11.74	55.94	5.37	2.48	6.08	1.91	2.88
2	12.77	16.92	47.87	6.75	4.80	5.94	2.87	.09
3	7.35	16.79	50.66	7.13	4.71	7.85	3.98	1.06
4	7.20	19.20	49.00	3.75	4.26	9.00	4.83	.92

64. Recarbonizing in Basic Bessemer.—Because of the danger of rephosphorization, as already explained, the basic slag must be separated as much as possible from the metal before recarbonizing. This is especially true because the bath is very liable to be hot, to be fully charged with oxides, and because the slag is richer in phosphorus than most of those made in steel manufactured by any other process. This necessitates recarbonization in the ladle.

65. Special Basic Bessemer Processes.—In England and Germany, where the basic Bessemer is commercially important, special forms of the process are in use, which, however, will not be discussed here, because they give no present indication of becoming commercially important in America.

THE CRUCIBLE PROCESS

66. General Remarks.—The crucible process is the oldest and simplest of the three principal ones, both in apparatus employed and in manipulation. It consists essentially in melting the stock in a crucible. It may be said that, at present, practically all crucible-steel melting furnaces are of the Siemens regenerative gas type.

67. The Hole Crucible Furnace.—The hole crucible furnace contains from two to twenty holes, taking four or six crucibles each. Each hole has its own gas and air regenerators, so that it is practically a separate furnace, but all the holes of a furnace have a common stack and main flues. Sometimes separate valves for controlling the gas and air to each set of checkers are provided, but more commonly the one set, *c* for gas and *d* for air, as shown in Fig. 8, are put in for the entire furnace. The dampers *f* are placed in the air and gas flues to the stack. Fig. 6 (*a*) shows a cross-section of the furnace and pair of regenerators, *a'* for air and *g'* for gas on each side of a melting hole; *p* and *p'* are gas and air ports, respectively; *i* are flues under checkers leading to the stack. Fig. 6 (*b*) is a longitudinal section on the line *AB*, showing four melting holes, the gas and air valves *a* and *g*, respectively, and stacks *s*. Each hole *o* has two or three (the latter number in the figure) movable arched coverings, or *bungs* *j*, of fire-brick held by clamps, which are lifted by hooks suspended on a trolley for charging and drawing the crucibles. Six or eight inches of coke dust is placed on the bottom of each melting hole, in the center of which is a hole *h*, so that if a crucible breaks, the steel runs into the vault *v* running the length of the furnace; this is cleaned out at the end of each week. The melting holes are separated by cross walls *k*.

68. Crucibles.—These are of clay and graphite. Clay crucibles are quite commonly used in England and in Europe

generally. In America, graphite crucibles are generally used. They cost more than clay, but last longer and are stronger, thus allowing larger ones to be used. The clay crucible is considered tougher at a steel-melting heat, but is very weak

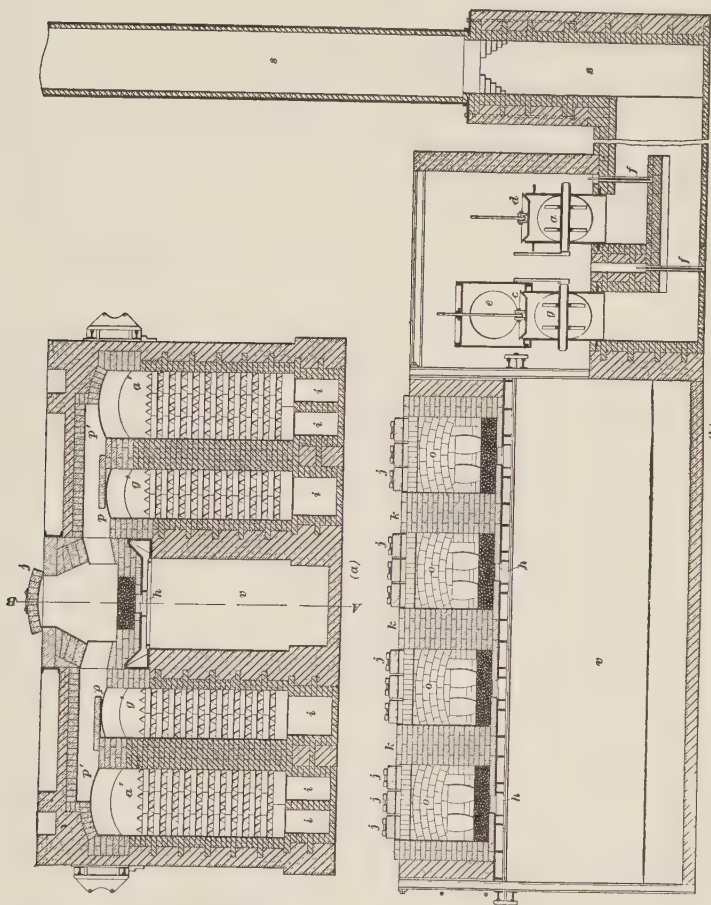


Fig. 6

when cold, the walls not standing the sudden contraction as well as the graphite, and if used over, must be returned to the furnace as soon as the charge is poured. They are more apt to break in the furnace also, causing a greater loss of steel

from this source. Graphite crucibles ordinarily hold from 80 to 125 pounds; the walls are from 1 to $1\frac{1}{2}$ inches thick. The dimensions of a 100-pound crucible are shown in Fig. 7. The

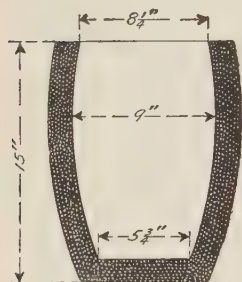


FIG. 7

life of a graphite crucible is from 3 to 8 heats usually, and frequently only one. This depends on a number of circumstances: the quality of the crucible, depending on the materials and manufacture; the kind of steel melted; they having a longer life with high-carbon steel; whether plunged into a very hot furnace or brought up more gradually, and the care and skill of the puller out in drawing.

69. Materials of Which Crucibles Are Made.—Crucibles are made from a mixture of about 50 per cent. graphite, 35 to 40 per cent. clay, and the balance sand. This varies with the practice of the manufacturer, the quality of the materials, and somewhat with the results desired. Graphite is the well-known mineral quite widely distributed. It is a form of carbon. The best is the Ceylon graphite, but much native graphite is used. It is found in many parts of the

TABLE VIII
ANALYSES OF SAMPLES OF GRAPHITE

Source	Carbon Per Cent.	Ash Per Cent.	Volatile Matter Per Cent.
Ceylon	99.68	.21	.11
Canada	97.63	1.78	.59
German (raw)	53.80		
German (dressed)	89.20		

United States, especially in Wisconsin and New York. The Ceylon product is the most valuable, not only owing to higher purity, but the laminated, or elastic, fibrous structure serves

to bind the matrix of clay more firmly than the amorphous graphite, which is believed to give much inferior results. It should be ground rather fine, as if left too coarse the crucible may become porous; if too fine, the walls are too dense and it does not expand or contract so quickly when exposed to sudden heating or cooling, and cracking results; heat also is conducted more slowly.

70. Table VIII gives the analyses of several samples of graphite. The more impure graphite is concentrated by dressing, consisting in air floating or treating by wet methods. The impurities accompanying it are generally iron pyrites, gneiss, or limestone.

Table IX gives analyses of standard clays and kaolins used in crucible making.

TABLE IX
ANALYSES OF CLAYS AND KAOLINS

Number of Sample	SiO ₂ Per Cent.	Al ₂ O ₃ Per Cent.	FeO or Fe ₂ O ₃ Per Cent.	Al ₂ O ₃ + Fe ₂ O ₃ Per Cent.	CaO Per Cent.	MgO Per Cent.	Comb. H ₂ O and Organic Mat. Per Cent.	Moisture at 100° C. Per Cent.	TiO ₂ Per Cent.	Alkalies Per Cent.
1	59.20	25.40	1.71		.52	.42	8.34	4.14		
2	46.99	30.04	2.14		.59	.55	11.69	4.17	3.00	.81
3	45.53			36.15	.25	.50	10.48	5.82		1.75
4	54.51	31.42	.68		.04	.43	12.37			.55
5	85.24			11.20	.72	.27		.45		1.26
6	65.80	22.09	1.58		.27	.32	7.09	.19		2.35

Of these samples, number 1 was the famous Crown brand from Kluengenbergl, Germany; 2 and 3, the Rhenish clay, Germany; 4, the Meisner clay, Germany; 5, kaolin from Staten Island; and 6, kaolin from Brandywine, Pennsylvania.

71. The sand used is the ordinary fire, or silica, sand having from 95 to 99 per cent. of silica with small amounts of alumina, alkaline earths, or combined water. Oxide of iron and alkalies are the most detrimental constituents, as they lower the fusing point, if present beyond a small amount.

72. Manufacture of Crucibles.—This includes the four processes of mixing, molding, drying, and burning. The ingredients are mixed by paste mixers and clay-working machinery to a thorough homogeneous mass, water being added to temper it properly; the batch when ready for molding contains about 22 per cent. of water.

Molding was formerly a hand operation, but at the present time is mostly done by various machines, jigs, presses, etc. The shapes, being quite simple, are readily formed by molds and shapers with the machines.

The drying of the green crucibles must be done very carefully, as the shrinkage is so great it may distort the crucible so as to render it useless or crack it. The average shrinkage is about 5 per cent. from the water used in mixing, but mostly from the combined water of the clay.

73. The burning requires the same care as the drying, and may be considered the final stage of the latter. It is done in some of the types of pottery kilns, the fuel being wood, gas, or coal; if the last, the sulphur must not be excessive, or the crucibles may be injuriously affected by its absorption. They are usually in the kiln 5 or 6 days—being fired at a gradually increasing heat for about 3, and the kiln or oven allowed to cool slowly for 2 or 3 days. The temperature reaches about 750° or 800° C. (say 1,400° or 1,500° F.), and is only required to take the entire shrinkage out of the clay. Coming from the kiln, the crucibles have a color ranging from a gray to a dark drab, depending partly on the temperature, but much more on the character of the flame maintained—if oxidizing to any extent the graphite will be burned from the surface, giving the light color of the clay body; if a reducing flame was kept during the firing, the crucibles will be darker colored, depending on the amount of graphite oxidized. Kilns are constructed to admit as little air as possible in excess of that required to effect combustion of the fuel, so as to reduce the oxidizing effect on the crucibles.

74. Crucible Charge.—The materials for making crucible steel are chiefly puddled iron or wrought iron and

steel scrap, together with the necessary amount of carbon, usually charcoal; manganese, as ferromanganese or oxide of manganese; or other additions. Blister steel, made by the cementation process of soaking iron bars with carbon in a converting furnace at a red heat, was originally used, and is even yet to a small extent in America, and quite largely in the original home of crucible-steel making, Sheffield, England. It is also held that the very highest grade of crucible steel can only be produced from blister steel made from the purest Swedish irons, even though other iron or soft steel may be produced of the same composition. It is impossible to give any satisfactory reason for this, and it has been attributed to prejudice and usage handed down through many years. As those best competent to judge, and to whose interest it would be to use other stock, insist that the higher priced Swedish irons give better tool steel, the fact can only be accepted, with the statement that our methods of examination are not perfect enough—whether chemical, physical, or microscopical—to show the distinctions or combinations that give this superiority. Comparatively little of the latter stock is used in this country in crucible melting, but the fact is of sufficient importance to be brought out prominently. The materials are usually very low in sulphur and phosphorus, as none is removed; it is an acid process, although basic crucibles have been used together with a basic slag to effect purification, but this has scarcely been more than an experiment, and has no promise of commercial value or technical importance.

75. The crucible is carefully filled with the stock while cold and then inserted onto the melting hole. The practice in England is to first place the crucible in the furnace, and when it has been heated somewhat, to introduce the charge by means of a sheet-iron funnel. As clay crucibles are generally used there, this allows a preliminary test before charging and defective ones may be thrown out.

Packing the cold crucible outside the furnace allows the stock to be more carefully placed, the larger pieces and the charcoal for carbonizing and any oxide of manganese or

ferromanganese used on the bottom, the smaller and closer fitting pieces are packed on top and likely serve to keep any gases from penetrating into the metal; also oxygen from the charcoal, lessening the loss of the latter. The crucible is then set in the melting hole by means of tongs. In the regenerative furnace they are set directly on the coke-breeze covering the bottom, or in a shaft furnace they are partially embedded in the glowing anthracite or coke.

76. Melting.—Melting is generally divided into the subdivisions of melting and killing, or dead-melting. With the crucible in the melting hole, a cover is put on it to keep out the gases. The temperature of the furnace is gradually brought up, if a gas furnace, by adjusting the gas and air supply, and draft, if necessary, to give the proper melting conditions. In the case of a coke hole, the solid fuel is piled up around the crucible to its top; if coke, it must be replenished two or three times during melting; anthracite, owing to its compact structure, does not have to be renewed for one melting. When the melter judges the charge about melted, the covers are removed and the contents of the crucibles examined to see their condition. The trained eye of the melter at once recognizes the condition of the steel, whether completely melted or if the temperature is too high or too low, and adjusts the furnace conditions accordingly. Sometimes the eye alone is depended on for temperature, or a light iron rod is introduced and stirred around in the metal, as in the open-hearth process. If the metal is very hot, little or no steel adheres to the rod or it may be melted off sharply at the end; if cold, the metal is sluggish and pasty, building up on the rod and adhering to it when withdrawn.

77. Killing, or Dead-Melting.—Holding the steel at a melting temperature until a change occurs that gives sound ingots or castings is known as *killing*, or *dead-melting*. The change is doubtless the simple one of the gases being boiled out of solution in the metal. This action is probably assisted by the absorption of silicon reduced by carbon from the SiO_2 of the crucible walls. The effect of killing is also held to be that

the silicon absorbed increases the power of the metal to hold gas in solution, enabling it to retain while solidifying any gas in the molten steel. This last explanation, while given by high authority, cannot be held to be proved or better grounded than the simpler one of boiling out any gas in solution. The latter is commonly accepted by practical steel metallurgists. Another important effect of the quiet period, during the killing action is that minute entangled particles (so minute as to be seen only with the microscope) of oxide, slag, etc., float to the surface. In the Bessemer and open-hearth processes, these "sonims" are never completely removed, and steel containing any of them is never of the highest quality.

The melting time is usually from $2\frac{1}{4}$ to 3 hours. This depends on a number of conditions, but principally (1) whether hard or soft steel is being made—soft (low-carbon) steel may require $\frac{3}{4}$ hour longer for melting than hard (high-carbon) steel, as the wrought-iron or other very low-carbon stock of the former melts at a much higher temperature than high-carbon stock; (2) the presence of manganese as oxide or in the metallic state shortens the time; (3) the furnace and its manipulation; (4) to a less extent than the preceding, the character of the stock aside from its composition, size of pieces, packing, etc.; the crucible—thickness of walls, their composition, etc.

There is no absolute line between the melting proper and the killing, as this is interpreted by the judgment of the melter, and the two periods overlap to some extent. Killing usually takes from $\frac{1}{2}$ to 1 hour—it may be longer or shorter, depending on conditions. Other conditions being the same, the hotter the furnace, the shorter is the time required for the killing; the purer the steel, the longer is the time required, doubtless owing to the higher temperature necessary to bring the desired condition, which may be merely the question of an ebullition to get the gases out; the lower the charge is in phosphorus, sulphur, silicon, manganese, or carbon, the more heat is required to give the same degree of boil. The entire time in the furnace from charging to drawing is generally from $2\frac{1}{2}$ to $3\frac{1}{2}$ hours, so that three charges are usually melted each 12-hour shift,

or turn, some little time being required between drawing and a subsequent charging for teeming and some fixing of the coke bottom in most cases.

78. Teeming, or Pouring.—The operation of teeming, or pouring, is accomplished by lifting the crucibles out of the melting holes by suitable tongs, picking them up with another pair, and pouring the metal into molds for ingots or castings. It is done almost universally by manual labor and is some of the hardest and hottest work of steel manufacture, as the pullerout must straddle the melting hole while withdrawing the crucible. Cranes with special tongs have been used to some extent for charging and drawing. The molds are of a size to hold the contents of one or several crucibles in the case of larger ingots, or a number of crucibles poured into one casting. Crucible-steel ingots of 90 tons have been made at the Krupp Works, Germany, requiring some 2,000 hundred-pound crucibles. In such a case, the most careful selection of the stock is essential to insure uniformity of the ingot; and perfect organization and discipline of the large number of men, so as to have the teeming done with sufficient promptness. Such ingots are made only there, and are used for armour plate. Many others of large size are made for high-grade forgings, such as engine shafts, propeller shafts, and other marine forgings, also guns and gun forgings. In America such materials requiring large masses of steel are always made of open-hearth steel. In the ordinary crucible shop, making tool steel mainly, the ingots are about 3 or 4½ inches square and the weight of one or more crucibles full. The molds are split lengthwise and held together by rings keyed on. Before teeming and while separated they are smoked by burning rosin, coal tar, or a smoky gas flame; this acts as a mold wash and gives a better surfaced ingot.

79. The loss in melting is very low—the least of any steel process—usually being from 1 to 3 per cent. of the weight of metal charged. The cost of melting is the highest of any process, approximately from \$7 to \$8 per ton, or from three to five times the labor cost in the Bessemer or open-hearth

process. The fuel consumption is high compared with the latter, about 1 pound of coal as producer gas per pound of steel, or about 15,000 cubic feet of natural gas per ton of steel melted; approximately, three times the amount required for open-hearth melting. The above factors, together with the limited output and the higher priced melting stock that must be used, explains the comparatively limited field of crucible steel, which is restricted to purposes where the first cost of the steel can be ignored—mainly tools, fine springs, saws, files, fine machinery parts, etc.

80. Regenerative Crucible Furnaces of Open-Hearth Type.—In Europe, especially in Styria and Austria, crucible furnaces are customarily built so that access may be had to them at the side instead of through the cover on the top. In this respect they are like the open-hearth steel furnaces, with the difference that the crucibles are put in and taken out through the side door instead of charging stock and tapping liquid metal there. The handling of the crucibles is done by means of a pair of tongs sufficiently long to reach into the farthest side of the furnace while still being supported at the fulcrum from an overhead trolley. The labor is greatly reduced in this way and especially the severe work of *pulling*. The men are removed from the heat during the work and it is possible to build the furnace so that a large number of crucibles may be treated at one time. In the roof of the furnace are holes covered with a brick in the usual way, through which the progress of the melting may be observed and tested. Some American manufacturers object to this open-hearth type of furnace because a large number of crucibles must be heated to the same temperature, and because it is slightly more difficult to remove any particular one of the crucibles at will without disturbing the others.

81. Superiority of Crucible Steel.—While no satisfactory reason has been given for the superiority of crucible over other grades of steel of like composition, the causes generally given are: (1) The purer stock melted; (2) as the crucible is covered during the melting, the gases from the

fire have very little chance to be absorbed by the metal. (3) freedom from "sonims," that is, minute solid particles in suspension.

It seems safe to say that to the conditions of melting are principally due the finer quality of crucible steel. In regard to the purer stock, there can be no direct comparison with Bessemer or open-hearth steel, as it is impossible to make either from the usual crucible stock without the use of other materials. But in the crucible process the melting receptacle is closed and all the gases are largely kept from the steel, whereas in the Bessemer process the air is blown through the molten metal, exposing it to the oxygen and nitrogen of the blast, the solid and gaseous products of combustion, some of which are undoubtedly absorbed, affecting the properties of the steel. In the open-hearth process almost the same conditions may be found, except that the gas for oxidation plays over the surface of the bath.

82. The widest ranges of composition are possible, and obtained regularly by varying the mixture. Carbon may be from .1 to 2.25 per cent., but as practically all crucible steel is used for tools or purposes requiring similar grades, we may restrict the carbon between .4 and 1.1 per cent. as covering the bulk of the product. Manganese varies between .1 and .75 per cent., but most grades are below .6 per cent.; silicon, between a few hundredths of a per cent. and .2 per cent., although considerable is made above this, not including silicon steel. Sulphur and phosphorus are each kept below .02 per cent. as a rule, but for less exacting purposes this is frequently exceeded, but seldom above .05 per cent. of either element is allowed. In the highest grades, where the purest Swedish melting stock is used, sulphur and phosphorus may not exceed .01 per cent. The effects of impurities are decidedly more marked in high-carbon steel than in low; the metal seems to be more sensitive, and the same amount of sulphur, phosphorus, or silicon influences the properties more.

83. Crucible steel is divided into different grades, according to the temper or carbon content, one temper generally mean-

ing .1 per cent. carbon. In determining the grades of the steel, the ingots are broken, or topped, and graded by the fracture. Sometimes color carbon tests are made, but most crucible shops use the fracture for grading purposes, and an experienced eye seldom misses the carbon more than .05 per cent. While no sharp subdivisions exist as to the uses to which different grades of crucible steel are put, the following shows them in a general way:

Steel of .5 to .75 per cent. carbon is used for battering tools, hot work, dull-edge cutting tools, etc.

From .75 to 1 per cent. carbon is used in steel for dies, axes, knives, drills, and similar purposes.

Steel from 1 to 1.5 per cent. carbon is used for razors, lathe tools, gravers' tools, little drills, etc.

Table X shows the analyses of various crucible steels and purpose used for.

TABLE X
PURPOSE AND ANALYSES OF VARIOUS CRUCIBLE STEELS

Use	Carbon Per Cent.	Manganese Per Cent.	Silicon Per Cent.	Sulphur Per Cent.	Phosphorus Per Cent.	Tungsten Per Cent.	Nickel Per Cent.	Chromium Per Cent.
Sledges, battering tools, etc.....	.50	.21	.210	.022	.020			
Hotwork shear knives, etc.....	.65	.20	.180	.020	.015			
Drills, reamers, dies, etc.....	.85	.18	.210	.015	.014			
Chisels, knives, lathe tools, etc.....	1.00	.26	.200	.010	.010			
Razor steel.....	1.30	.22	.200	.006	.009			
Dies, graving tools, etc.	1.30	.16	.140	.014	.012			
Cutting tools, etc. (self- hardening).....	.94	1.50	.160	.015	.012	3.40		
Krupp armor.....	.28	.32	.055	.016	.015		3.60	1.75

The best all-around tool steel is between .9 and 1.1 per cent. carbon, and is capable of being adapted to a wider range of uses than any other grade.

MANUFACTURE OF STEEL

Serial 2053D

(PART 4)

Edition 1

ELECTROMETALLURGY

ELECTRICAL PROCESSES

1. There are many localities where coke is so costly that the production of pig iron from ore is commercially impossible notwithstanding abundant deposits of iron ore in the vicinity. One of these localities is Sweden, where the unusually pure ores are smelted with charcoal. This is indeed the only locality in the world where electric smelting of iron has proved commercially practicable up to the year 1921. It has been tried in parts of Canada and the United States, and in other localities remote from coking regions. Technically, the process is an excellent one, but the enormous cost of electricity in amounts sufficient for the purpose has rendered the industry commercially impossible. It should be understood that electricity is used solely for the purpose of providing the heat necessary for the process. The reduction of iron from the ore is accomplished by means of carbon, usually in the form of charcoal. This one statement covers all the principles of electric smelting, but, of course, the details of the furnace vary greatly from those of the iron blast furnace.

2. For more than 60 years the electrolytic production of iron has been a technical success, but it has been a commercial success only for a very few years. One plant is located in France and another in Illinois. Its future, however, appears

to be bright. It is interesting to note how the metallurgy of most of the metals is tending to the electrolytic process for the production of pure material; for example, copper, zinc, lead, and iron. In the French process iron is deposited from a solution of ferrous chloride, $FeCl_2$, on revolving mandrels. It is more than 99.9 per cent. pure; it is annealed in an electric furnace (to avoid contamination by the gases of a coal furnace), drawn a few times through a die and sold as commercial boiler tubing.

In this process the anode is made of pig iron and steel scrap, which, therefore, comprise the raw material of the process. The purpose is to produce finished boiler tubes of great purity for resistance to corrosion. Instead of starting with pig iron or steel scrap as the material, it is technically quite feasible to form a ferrous-chloride solution direct from iron ore and then to use this as the electrolyte. Technically, the use of iron-sulphate solutions as electrolytes is entirely satisfactory, but commercial processes are not at present operating on this principle.

The electrolytic process, as compared to the electric smelting process, has the advantage of using very much less electric power. The intense temperature necessary for smelting iron ore involves the expenditure of large quantities of electric energy, which is the most perfectly and easily controlled, but, on account of its cost, is objectionable from the commercial standpoint. Even electric energy at a low price, say less than $\frac{1}{2}$ cent per kilowatt hour, makes electric smelting a very costly operation.

MANUFACTURE OF STEEL IN ELECTRIC FURNACES

3. The production of electric steel is now an accomplished commercial industry in all the important iron-working countries. The important principle is that electric energy is used as the source of heat. It must be emphasized that electricity has no other function in the process. It can neither oxidize impurities nor reduce iron from the slag in any of the present types of electric steel furnace. The advantages of using electrically produced heat are:

1. Almost any desired degree of temperature can be maintained, thus getting the steel as liquid as may be desired and also maintaining in the liquid form slags which would be pasty and inoperative in all other types of furnace.

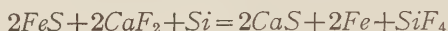
2. By avoiding the burning of coal, a furnace atmosphere can be maintained which is either oxidizing, reducing, or neutral. In the open-hearth furnace a high degree of temperature cannot be obtained without maintaining an oxidizing atmosphere in the furnace.

4. Electric-Furnace Temperatures.—In electric furnaces caution must be exercised to keep the temperature down to reasonable limits rather than (as in the open-hearth furnace) to keep it up to the desired point. Unfortunately, too high a temperature is altogether too common in electric-furnace steel manufacture, with the result that the quality of the steel is seriously affected and the life of the furnace lining is shortened. The electric furnace actually requires greater care and greater skill for successful technical operation than any other type of steel furnace. Even the best of operators are unable always to make as high a quality of steel in the electric furnace, for some purposes, as can be made in the crucible. Nevertheless, the quality of electric steel in general should be equal to that of crucible steel.

The high temperatures attainable in the electric furnace make them especially desirable for steel castings where very liquid steel is often an advantage. A second advantage of the high temperature attainable is the possibility of maintaining a slag so high in lime, that not only phosphorus, but sulphur also will be readily absorbed. Thus, these two objectionable elements in electric-furnace steel can be reduced as desired. It has already been learned that the absorptive power of slag for an element is not in itself sufficient to effect its removal. Phosphorus must be oxidized before it can be absorbed by any slag and sulphur must be converted to CaS .

5. Removal of Sulphur.—In the arc type of electric furnace, where a slag very rich in lime is used, the prevailing factors make it possible to form calcium carbide by throwing

coke on the surface of the slag. This calcium carbide is reacted upon by the steel bath, with the formation of CaS , which (as already noted in *Manufacture of Iron*) will dissolve in the slag. In the induction type of electric furnace, desulphurization may be performed by the use of fluorspar or calcium fluoride, CaF_2 , as will be explained later. The reaction which takes place between fluorspar and iron sulphide may be written



6. Dead-Melting in the Electric Furnace.—The possibility of maintaining a reducing or a neutral atmosphere in the electric furnace, and of maintaining reducing conditions in the slag and bath, after adding coke to the slag as previously described enables the steel to be *killed* in the electric furnace just as in the crucible. This killing consists:

1. In removing from the steel the oxides which are dissolved in it or held in a state of suspension, like colloids. Examples are, FeO , MnO , and SiO_2 . These may be removed either by allowing the steel to lie quiescent in the furnace, so that the oxidized particles separate by gravity, or else by reducing them chemically through the influence of reducing agents in the slag.

2. In allowing the gases which slowly rise to the surface, about 30 minutes to escape; also a quiescent condition. If these gases do not escape, they might produce harmful blow-holes.

7. Operations Performed in the Electric Furnace. Because of the high cost of electric energy converted into heat, the larger steel works perform only the minimum necessary operations in the electric furnace. It should be emphasized that the electric furnace has never developed any advantages except high temperature and the possibility of a neutral or a reducing atmosphere. Likewise, the electric-furnace operation costs more than that of other common furnaces. Sulphur removal is the one thing that can be accomplished in the electric furnace more cheaply than in any other type of furnace. Therefore, the large steel works

use the electric furnace solely for the purpose of superrefining, by which is meant the removal of sulphur and killing the steel, subsequent to the usual purification in one of the other furnaces.

However, steel scrap may be melted in an electric furnace, purified, and made into castings or into high-priced special steels. Where steel scrap is relatively cheap and a high price can be had for the product, this is a commercial process. Likewise, steel scrap may be melted in an electric furnace and advantage taken of tungsten or other costly elements which it contains, and which would be oxidized out if the steel were melted in the open-hearth furnace. The very high price obtainable for tungsten steel makes this a commercial process.

8. Types of Electric Furnace.—There are two types of electric furnace, namely, the arc type and the induction type. In the arc type of furnace are used two or three carbon electrodes which project through the roof of the furnace and are immersed in the slag. A myriad of tiny arcs travel between the electrodes and the bath, and these produce the temperature required in the furnace. Sometimes there are electrodes in the bottom of the furnace, as well as above it, and the current travels through the bath. In other forms of electric-arc furnaces, overhead electrodes are used solely for bringing the electricity to the furnace. In either event, alternating current is customarily used.

9. Induction Furnace.—In the induction furnace the metal is heated entirely by heat generated through the high resistance offered by the metal. In this respect it is similar to the usual type of incandescent electric light in which the temperature comes from the resistance of the filament. Because a liquid bath of steel has a relatively high electric resistance, high temperatures can be secured by passing powerful currents through the metal. One advantage of this type of furnace is the accurate control of the temperature, but the operation is costly on account of the loss of electricity in the transfer.

10. In Fig. 1 is shown a vertical cross-section of the *Kjellin furnace* in which *b* represents the circular crucible in which the melted steel lies, *c* the iron transformer core, and *a* the coil surrounding one leg of this core. The primary current traversing the coil *a* and magnetizing the core *c* induces the secondary current in the circular crucible ring *b*. The resistance of the melted metal in the crucible *b* to the passage of this secondary current creates the heat for carrying on the operation. In point of fact, it is not usual to use a single ring of metal. By using two intersecting rings, a central bath of much greater size can be obtained. This type of furnace is still in process of development. It is difficult to desulphurize with it and yet it has the very great advantage of avoiding the high electrode expense of the arc type.

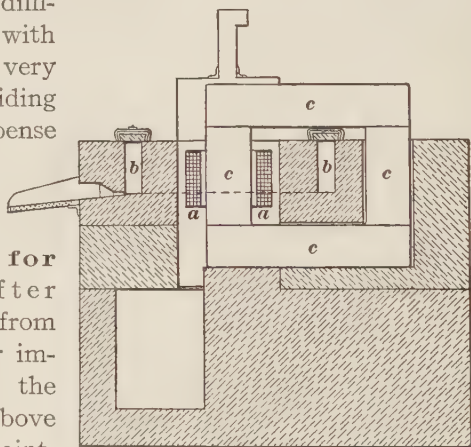


FIG. 1

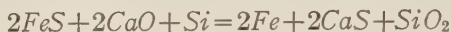
11. Operation of Electric Furnace for Superrefining.—After steel has been purified from phosphorus and other impurities, and while the carbon is still slightly above the desired finishing point, it may be poured out of the open hearth furnace and transferred by means of a ladle to the basic hearth of the electric furnace. Here it is at once covered with a slag which is so high in lime that it would be unmeltable in the open-hearth furnace. In practice, the slag is usually made up of about 4 parts lime and 1 part of silica in the form of sand. To this may be added as much as one-third of its weight of coke dust. The slag is at first brown in color, because of its content of oxides of iron and manganese. More lime, fluorspar, sand, and coke dust, may be then added and the slag should soon lose its metallic oxides and become white in color. This indicates that the deoxidation of the bath is

complete. If the temperature has been high it may also be assumed that the sulphur has been reduced to a very low point. The final slag may contain up to 20 per cent. silica and about 70 per cent. lime and magnesia. It may contain as much as 1 per cent. or more of sulphur in the form of CaS , and also compounds like alumina, which get into it with the sand. It should contain less than 1.50 per cent. of manganese plus iron. At this point the steel should likewise be completely killed. It should then be recarbonized in the furnace and tapped. The tapping must be done through a tap-hole under the level of the slag and none of the latter must be permitted to get into the ladle.

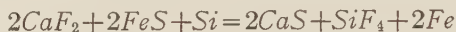
12. Operation When Melting Scrap.—In the induction type of furnace a ring of metal is almost always left in the bottom of the crucible in order to start the secondary current at the beginning of a new operation. The scrap is piled on top of this and the furnace operation commenced. When melted metal is charged in to the induction furnace, this use of a ring is, of course, unnecessary.

The melting of scrap in the electric-arc furnace results in a great deal of waste of electricity on account of lost contacts, arcing between the particles of scrap, and tremendous variations in the energy absorbed. If the scrap consists of ordinary carbon steel, the melting is followed by an oxidizing period during which the phosphorus and carbon, as well as any excess of silica and manganese that may be present are eliminated. Oxidation is almost all performed by means of iron ore added to the slag. When this oxidizing period has continued long enough, the slag is tapped and raked off. As the electric furnaces are almost always of the tilting type, the removal of the slag is a comparatively easy operation. This oxidizing period is then followed by a reducing period, which is similar to the desulphurizing and killing operation previously described. This killing operation makes the electric steel superior to that produced in the Bessemer and open-hearth furnaces. It should be noted that, in the induction furnace, calcium carbide cannot be made for desulphurizing, but

advantage is taken of the silicon in the bath, which, at the very high temperatures of the electric furnace, will reduce calcium from lime. As follows:



Desulphurization in an induction furnace can also be accomplished by means of fluorspar:



13. Recarbonizing.—Recarbonizing takes place in the furnace, and is much simpler than in the Bessemer or open-hearth process, because there is almost no loss of metalloids by oxidation of compounds, either in the metal or in the slag. After recarbonizing, the metal must be brought to the proper temperature, and it is then tapped without any admixture of slag whatever.

STEEL CASTINGS

14. General Remarks.—The manufacture of steel castings is an important branch of the industry, both technically and commercially. Casting steels are produced by exactly the same methods and apparatus as other grades of steel, similar stock being used, in either the acid or basic open-hearth, Bessemer, crucible, or electric processes. As a matter of fact, the bulk of steel castings are made by the open-hearth process.

The basic open-hearth steel is used to an increasing extent, but the acid open-hearth steel, side-blow converter steel, crucible, and electric steels are all superior to basic steel in quality, on account of oxides, blowholes, and danger of rephosphorization in the latter. Due especially to earlier troubles with the basic open-hearth process, makers have not had the confidence to use it, especially when the spoiling of the steel means the further loss of the foundry labor of molding, etc. The regular Bessemer steel is not used in any shop on steel castings exclusively, but some plants making ingots make occasional casting heats. Several modified Bessemer processes have been used in regular casting practice. One, the Tro-

penas, which has met with much success, has been described in a preceding Section.

15. Solidity.—In making castings it is essential that the steel shall lie comparatively dead in the molds, with little action, otherwise the product will be more or less honeycombed with blowholes caused by escaping gases. To overcome this, the special knowledge and art of the maker of steel castings are necessary. It is accomplished by the use of deoxidants, or deoxidizers, which remove the gases while the steel is molten, or increase the power of the metal for holding them in solution.

Solidity is further due to a riser or sink head made on top of the casting, so that as the latter cools and contracts, metal flows in from the sink head and fills up the shrinkage cavity. The weight of the sink head depends on the size and character of the casting. It may amount to 50 per cent. of the weight of the latter, but is usually from 5 to 20 per cent. As its function is to supply molten metal to the contracting casting, it must be large enough to remain open until the casting sets, and also have enough liquid steel to supply the demands due to shrinkage of the latter. The deoxidizers, silicon, aluminum, and manganese, remove the gases or increase the solvent power of the steel for them. While their action is not absolutely understood, they produce solidity by either or both of these actions. Melted steel has gases in solution, and its power to retain them is largely dependent on the temperature. Killing in the crucible removes the gases (possibly with the aid of silicon), and solid ingots or castings are produced. This effect is reached in open-hearth or Bessemer castings by the use of silicon or manganese in the form of some of the recarbonizing alloys or additions given under Recarbonizers, or by adding metallic aluminum, all of which come under the general head of recarbonizers or deoxidizers. An excessive amount of these cannot be used, or the metal will be made brittle from the over-dose or possibly from retaining too much of the gases; yet it will be perfectly solid and free from blowholes. The latter may not lessen the

strength and toughness of castings to the extent that their presence would indicate, but in parts to be machined or to have finished surfaces, their presence is entirely unallowable. Carbide of silicon is used in some steel foundries as the sole source of silicon and part of the carbon; in others, silico-spiegel for silicon and manganese, or ferrosilicon for the silicon, and spiegeleisen or ferro-manganese for the manganese.

16. Composition of Casting Steel.—The composition of the steel depends, as in other grades, on the use to which the steel is to be put. For very soft castings, where great toughness and ductility are required, but not high tensile strength, the carbon may be as low as .12 per cent.; where stiffness and great strength are wanted and ductility is of less importance, carbon may be as high as .8 per cent. For ordinary purposes and covering castings for most uses, the carbon is from .2 to .5 per cent. The amount of silicon will vary with the carbon, as a rule, from .1 to .4 per cent.—the low-carbon steel having the less, and the harder (high-carbon) the more, silicon. The usual range is from .2 to .3 per cent.

17. The amount of manganese present is usually .5 to .8 per cent., but it may be outside these limits. Some castings are made with 1 to 1.25 per cent. of manganese, and are air-quenched in order to toughen them; that is, they are heated to a cherry red and allowed to cool in the air. The amount of phosphorus may reach the usual Bessemer steel limit of .1 per cent., but the best castings should not exceed .04 per cent., which is readily attained in basic practice, but in the acid requires the use of higher-priced stock. Phosphorus is held to produce brittleness under shock, and is, therefore, especially objectionable in castings subject to sudden strain or shock.

The usual range of sulphur is from .025 to .05 per cent., and should not exceed the latter very much. Aluminum is added frequently as a solidifier (deoxidizer), equivalent to .02 to .03 per cent. (from 4 to 10 ounces to the ton of steel), but this is mainly oxidized to Al_2O_3 and goes into the slag, and

the small amount in the steel cannot be accurately determined. As in all ordinary steels, carbon is the principal strengthener, manganese, silicon, and sometimes aluminum give solidity and freedom from blowholes.

Nickel-steel castings to a limited extent are made where greater strength and toughness is wanted than is given by

TABLE I
ANALYSES OF STEEL CASTINGS

Kind of Casting	Carbon. Per Cent.	Manga- nese. Per Cent.	Silicon. Per Cent.	Sulphur. Per Cent.	Phos- phorus. Per Cent.
Machinery castings...	.18	.30	.28	.032	.082
Machinery castings...	.24	.60	.30	.040	.045
Rolls.....	.48	.45	.31	.036	.032
Rolls.....	.75	.80	.28	.040	.050
Pinions.....	.26	.45	.27	.056	.060
Pinions.....	.44	.74	.33	.045	.092

plain carbon castings. Nickel steel is used for pinions on heavy rolling mills or for parts subject to sudden and severe shock. The nickel is usually from 3 to 4 per cent. in such steel. Table I gives the analyses of some steel castings.

DEFECTS IN STEEL INGOTS

18. Segregation.—Unfortunately for the metallurgist and user, large masses of steel are never absolutely homogeneous, and frequently wide variations are shown between different parts of the same ingot. This difference in the composition, or the tendency of certain elements to concentrate is known as *segregation*. Occasionally it is so serious as to render a part of the ingot unfit for use, but generally, when proper care has been exercised in making and handling the steel, its effects are not dangerous. As the elements tend to segregate, or become enriched in the portion of the metal last to solidify or *freeze*, which is at the top and near the *pipe*, the cutting off of this portion gets rid of the worst of the

segregation. With other conditions the same, the larger the ingot, the greater is the segregation. With very heavy ingots for armor plate, forgings, or where great homogeneity and reliability are required, a portion of the top is cut off for scrap or to be used for inferior purposes.

The cause of segregation is fairly well understood; it is due mainly to the lower melting points of the carbides, phosphides, and sulphides of iron and the sulphide of manganese. As the metal freezes, these, by remaining fluid at lower temperatures, segregate out and collect in the part of the ingot last to solidify, which is usually the upper central part, approximately the upper fourth or fifth of the ingot. It occurs without any regularity and the laws governing it are not understood. In general, the greater the percentage of metalloids, the greater is the liability to segregation and the more serious it will be. If the steel in the ingot could be instantly solidified, without otherwise injuring its properties, segregation would be avoided; so that slow cooling favors the separation of the impurities; and as their specific gravity is less, they have a tendency when once formed to rise through the body of molten metal.

19. The term *segregation* should be confined to those irregularities occurring after pouring into ingots or castings, as distinguished from irregularities in the furnace or ladle. The latter may be due to careless melting, or addition of recarbonizers in such a way that they are not distributed uniformly throughout the metal; while evils of this kind have been charged to segregation, it is well established that a thoroughly uniform metal is generally gotten in the ladle and there is little excuse for variation there. The same cannot be said of the steel after it has been poured, as the conditions under which segregation takes place are only partially under the control of the metallurgist. The condition favoring homogeneity is that the steel remains molten the least possible time permissible. If made to solidify too quickly, as bad or worse consequences follow—cracking, the formation of excessive blowholes, and piping. Casting at

TABLE II
EXAMPLES OF SEGREGATION

Description	Carbon. Per Cent.	Phosphorus, Per Cent.	Sulphur. Per Cent.	Silicon. Per Cent.	Manganese, Per Cent.
Bessemer ingot, weighing 4,500 pounds { top..... middle..... bottom.....	.10 .08 .08	.145 .110 .105	.110 .085 .075	.012 .009 .009	.47 .46 .45
Acid open-hearth ingot, weighing 2,000 pounds { top..... middle..... bottom.....	.55 .38 .37	.060 .060 .058	.048 .042 .042		.54 .48 .45
Acid open-hearth ingot, weighing 2,000 pounds { top..... middle..... bottom.....	.26 .14 .13	.114 .060 .049	.067 .027 .025		.37 .33 .34
Basic open-hearth ingot, weighing 3,000 pounds { top..... middle..... bottom.....	.45 .25 .20	.020 .020 .015	.030 .025 .023		.37 .38 .36
Basic open-hearth ingot, weighing 6,000 pounds { top..... middle..... bottom.....	.26 .18 .18	.040 .024 .024	.054 .035 .030		.44 .39 .39

excessively high temperatures or in very large masses is the principal cause of segregation, and keeping both within reasonable limits is the chief remedy for it. Both act by keeping the steel longer in the liquid state, allowing more favorable opportunities for the compounds of lower melting points to separate out, mainly the carbides, phosphides, and sulphides; manganese and silicon segregating to a less extent. When excessive segregation of one element is found, others are to be looked for with it, but this does not always occur. The use of aluminum, by lessening the time the steel remains fluid in the molds and causing it to solidify more evenly, diminishes the evil.

20. In Tables II and III, examples are given of some extreme cases. It must not be assumed that all steel segregates seriously because no examples of uniformity are given. While all masses of large size vary somewhat and absolute homo-

TABLE III
SEGREGATION OF STEEL CASTINGS

Description	Carbon. Per Cent.	Phos- phorus. Per Cent.	Sulphur. Per Cent.	Man- ganese. Per Cent.	Silicon. Per Cent.
Broken steel roll, center.....	1.25	.048	.060	.58	.15
Broken steel roll, outside.....	.90	.030	.048	.55	.13
Broken steel roll, end opp. break...	.44	.035	.042	.52	.14
Broken steel roll, center.....	.65	.331	.165	.85	.33
Broken steel roll, outside.....	.44	.070	.046	.54	.27
Broken steel roll, end.....	.19	.063	.036	.52	.24
Steel pinions, center.....	.17	.060	.056	.45	.27
Steel pinions, outside.....	.26	.050	.050	.44	.27

geneity is never expected, yet for practical purposes steel may be assumed as being uniform, the many exceptions either proving the rule or are to be explained by special circumstances in the manufacture, chiefly casting temperature and mass.

21. The variation is not entirely from top to bottom, but also from outside to center—a shell chilling next the iron

mold first and the interior of the ingot remaining fluid, the carbides, phosphides, etc., owing to their lower melting points, are pushed out of the solidifying mass and enmeshed in the gradually freezing steel. Table III indicates the extent of segregation in some steel castings.

The foregoing castings weighed from 4,000 to 6,000 pounds and afforded opportunities for segregation similar to large ingots. In steel castings of medium and small size, segregation is practically absent, as the mass is liquid a much shorter time. It is generally less in castings, as the metal is partially killed with silicon or aluminum, so that the freezing interval is less.

22. Blowholes.—Blowholes are small cavities, usually spherical in shape, formed in the ingot as the steel solidifies, and are caused by bubbles of gas unable to escape through the freezing mass. They may to some extent be due to air drawn down mechanically by the stream of metal while pouring, but it is generally accepted that they come from gases either formed or escaping from solution, as the metal sets in the mold. The principal gases are nitrogen, hydrogen, and carbon monoxide. Blowholes in low-carbon steel cannot be prevented and, if deep-seated, do not cause injury to the steel, as the inner surfaces of the cavities cannot oxidize and are readily welded together by subsequent rolling or forging. The lower the steel is in carbon, other things being the same, the more blowholes will be formed; high carbon, silicon, or manganese usually cause the steel to lie quiet and be free from blowholes, because they have freed the metal from oxides. Dissolved oxides are certain producers of gases which in turn are very liable to cause trouble.

23. Dead-melting decreases the number of blowholes, crucible steel being almost free from them; any addition causing the steel to lie quiet (kill or deaden it) will decrease them. Blowholes are not to be regarded as altogether objectionable, but rather as a necessary condition, especially in the soft and medium grades of steel, and their removal or prevention may be harmful. When blowholes form, they cause some

expansion within the body of the metal, which counteracts the contraction of the steel in freezing and cooling. In this way blowholes decrease the volume of the pipe formed.

If a steel ingot be broken, there will be found a solid skin, usually from $\frac{1}{2}$ to 1 inch thick around the outside, depending mainly on the temperature of casting; with excessively hot steel it will be very thin, and with steel at normal casting temperature it will be thicker. Next to this skin are the blowholes, or honeycomb, extending around the ingot; they may spread well into the middle, depending on the kind of steel and the temperature in pouring. As stated above, their volume will be greater with soft steel. If brought too near the surface by very hot steel, the skin is so thin that in reheating and rolling it is removed or rolled into the honeycomb or blowholes, exposing these on the surfaces of plates. These constitute a serious defect known as *pitting*, from the small holes, or pits.

24. Pipes.—Pipes are shrinkage cavities in the upper central parts of ingots, formed after the outside has solidified. The exact relation between blowholes and pipes cannot be explained, but, in general, steel that does not form blowholes pipes more or less, and vice versa. As examples of this, crucible steel is free from blowholes, but pipes more or less deeply; high-carbon or silicon steel exhibits the same tendency; also, conditions in the same steel that lessen the tendency to form blowholes generally increase the liability to pipe; the addition of silicon or aluminum for quieting steel lessens the blowholes, but induces piping, and this may be quite marked even in soft steel, if an excessive amount of silicon or aluminum is added. As a rule, the fewer and smaller the blowholes, the greater the piping. Extremes of casting temperature—either too hot or too cold—increase both blowholes and piping.

25. Prevention of Ingot Defects.—A uniform casting temperature, finishing the heats with a steel and slag, that does not contain too much oxygen; care in recarbonizing, in order that the recarbonizer may be well mixed with the bath of

metal; keeping the top of the ingots or casting as hot as possible, in order to draw the pipe and segregation to the highest possible point; and even stirring the top of the casting with a rod, to keep it open and delay the formation of a solid covering over the top, will all help to prevent deep pipes and segregation, while the three precautions first mentioned will especially prevent skin blowholes in low-carbon steel.

EFFECTS OF THE ELEMENTS USUALLY PRESENT IN STEEL

26. General Remarks.—Only those elements commonly found in ordinary commercial steels will be considered here, all reference to special or alloy steels being treated elsewhere. The constituents affecting the properties, and those usually present in ordinary carbon steel, are carbon, manganese, sulphur, phosphorus, silicon, and oxide of iron; copper and nickel, being present in considerable steel, will be included. While each element has its own distinctive effect, it is frequently difficult or impossible to determine just what this is in given steels, as the effect will be so modified by the amount of one or more of the others present or the almost endless combinations of different percentages of the elements. Conditions in the making and subsequent treatment in rolling, hammering, cooling, etc. mask or exaggerate the influence of given amounts. There are, however, certain well-defined effects for the different elements, and these will be given as generally accepted by metallurgists.

27. Carbon.—By far the most important of the elements in steel is carbon. It combines in all proportions up to about 2 per cent., but seldom exceeds 1 per cent., except in tool or special steels. It is readily absorbed at or above a red heat and the metal does not have to be liquid; manganese increases the affinity of iron for carbon. In common steel the carbon is present as combined carbon, though small amounts of graphite may occasionally be present. Carbon increases the strength and hardness, but decreases the ductility. Strength is increased up to .9 or 1 per cent. carbon;

above this it diminishes; the melting point of steel is lowered by carbon; the nearer we approach pure iron, the higher is the melting point. An increase of strength and a loss of ductility and elasticity go together with carbon in steel.

28. Manganese.—Manganese increases the strength and ductility of steel, but its chief function is the effect it has on other elements, mainly oxygen or oxides and sulphur, acting as an antidote for *red shortness*—brittleness at a red heat. Manganese alloys are used to recarbonize and remove oxygen from the bath, although some of the latter always remains, and the residual manganese neutralizes its effect and that of sulphur. Silicon and phosphorus tend to produce coarse crystallization, and manganese seems to prevent this, giving a free-grained fracture. It increases the rolling qualities or hot working of any kind, that is, gives *hot ductility*; it also allows steel to be heated hotter without injury. Steel with very low percentage of manganese will crack along the edges, in rolling or forging, whereas the same metal with higher manganese will usually work satisfactorily. While manganese is not a panacea for bad steel, nor will it cover up the effects of improper working or too high impurities, it is the most essential addition in correcting necessary evils—for example, the presence of sulphur and oxygen or oxides. In soft steel, manganese ranges from .3 to .6 per cent.; in hard and medium steels, rails, forgings, etc., from .4 to 1 per cent. While no definite rule exists as to sulphur and manganese, approximately 8 to 10 times as much manganese as sulphur is allowed.

29. Sulphur.—The effect of sulphur is felt when working at a red heat, for with it the metal cracks and tears and welds much less readily. Castings have a greater tendency to crack in weak spots while cooling from the liquid state to black heat when the sulphur is above .05 per cent. The percentage allowable will depend on the steel and the purpose for which it is to be used. In a great deal of ordinary steel it may reach .08 per cent. without serious injury, but should always be kept as low as possible; in other steel, for plates,

etc., it frequently must be kept below .03 per cent. The cold properties of steel are not as much affected by sulphur as are its properties at red heat; the strength is increased slightly. Steel high in sulphur will seldom get through the rolling mill without cracking badly. That the sulphur is exceedingly injurious for very many purposes is seen from the fact that red shortness will throw it out in the mill from cracking, etc. For wood screws and generally where the product must be threaded, rather high sulphur, say up to .1 per cent., is an advantage. This appears to be due to the fact that the steel is less tenacious and does not gall or tear as does tougher steel; it also takes a better polish. Manganese also helps in the latter process.

30. Phosphorus.—In some respects phosphorus is the most objectionable impurity in steel. Its most marked effect is in producing a cold-short metal or one brittle at ordinary temperatures and brittle under shock. It does not greatly affect the hot working unless present in excessive amounts—.2 per cent., or higher. It is objectionable, as it gives a coarse grain to the steel and lowers the point to which it can safely be heated. Up to .12 or .13 per cent., phosphorus increases the strength but lowers the ductility. The greatest objection is that high-phosphorus steel is treacherous and is liable to break under even small loads if they are suddenly applied. The behavior of high-phosphorus steel is uncertain and whimsical throughout, and for this reason its use is always perilous. The ordinary limit in Bessemer steel is .1 per cent., but some Bessemer is made as low as .075 per cent. phosphorus; by the basic process it is usually made below .03 per cent. Phosphorus is not known to be a benefit to steel under ordinary circumstances. However, a high phosphorus content will prevent welding in those cases where it is deemed undesirable.

31. Silicon.—Silicon is generally absent in soft steels, while in railsteel and castings it is present from .1 to .4 per cent. In castings, it is added more to produce solidity than for any effect on the physical properties. Soft and medium

steels, for plates, structural steel, etc., seldom contain over .05 per cent. of silicon and usually less than half of this. There is some uncertainty and difference of opinion as to the exact effect of silicon, but generally it does not affect strength or toughness in amounts usually present. It increases the stiffness, and is used in some heavy springs requiring this feature. It also hardens the steel, and this is commonly accepted as the beneficial effect in steel rails, causing them to wear longer. It increases the size of the steel crystals, and steel with a few per cent. of silicon will show crystals as large as a finger nail. Any considerable percentage of silicon interferes with working at redness, welding, etc., and it is usually a cause of red shortness, although some high-silicon steels forge well. All the alloy steels having much silicon must be worked at low heats.

32. Oxides or Oxygen.—Oxides or oxygen produce somewhat the effect of sulphur, as cracking, and red shortness. Manganese removes them partly or almost completely, depending on conditions in recarbonizing, and it neutralizes their effect in the steel. The presence of oxides or oxygen is greater in soft steels or those that are low in manganese, as they have the oxidizable elements to seize in harder steels and thus may be removed as gases or solid compounds to go to the slag.

33. Copper and Aluminum.—Copper has been supposed to produce red shortness in particular, but later investigations disprove this, unless it is accompanied by high sulphur, say .075 to .1 per cent. In amounts up to .5 or .75 per cent., copper has little effect on the cold properties of steel. It adds slightly to its ductility, and only affects hot working when sulphur or some other red shortener is high. A small amount of copper—less than 1 per cent.—reduces corrosion.

With the amounts of aluminum added as a deoxidizer, it is seldom that even a trace of it is found in the steel. Added in larger amounts, it increases strength somewhat and lowers ductility. Aluminum finds no use except as a quieter in the proportion of from 2 to 5 ounces per ton of steel; and this unites with the oxygen of the bath and passes into the slag.

ALLOY STEELS

34. General Remarks.—By alloy steels are meant steels that owe their special properties to the presence of elements other than carbon. The carbon, however, generally plays an important part in these special or alloy steels, while ordinary or carbon tool steels owe their properties almost wholly to carbon.

35. The principle from which the advantages and unusual qualities of alloy steels arise is based almost entirely on the changes which occur in steel in cooling, and which are represented by the equilibrium diagram, Fig. 4, discussed further on under the heading of Metallography. Therefore this part of the alloy-steel question has been included under the heading of metallography. The extraordinary effects of alloying elements on steel may be summarized under the following heads:

1. They interrupt or delay the critical changes which steel ordinarily undergoes in cooling through the range of red-hot temperature.

2. They affect the crystallization; in most cases, by preventing the growth of the iron crystals to large size.

3. They alter the effects of temperature; that is, they give red-hot steel the strength which it usually enjoys only at black heat.

36. Manganese Steel.—The extraordinary properties produced by the addition of alloying elements are exemplified very well in the case of manganese steel, which contains 12 to 15 per cent. of manganese and 1 to 2 per cent. of carbon. Manganese is commonly used in steel up to about 1.25 per cent. for removing oxygen and for neutralizing the bad effects of whatever oxygen may be left, as well as of the sulphur content. When the manganese is increased to about 5 per cent. the steel becomes brittle and worthless. At about 7 per cent. an entirely new set of properties begins to appear. These reach a practical and commercial maximum at about 14 per cent. manganese.

Manganese steel of this composition, when slowly cooled from casting temperature, is almost as brittle as glass; but, if it be reheated to about 1,850° F. and rapidly cooled by plunging into water, it loses its brittleness and becomes one of the very ductile steels, with a tensile strength about three times that of ordinary ductile carbon steel. When first discovered, it was the only substance known to man which was both unusually strong and unusually ductile at the same time. It was also the only known substance which was hard without being brittle. That is to say, it is so hard that it is usually machined by means of emery grinding wheels, and yet it is so tough that it can be not only rolled and forged, but bars of it may be even tied into knots.

37. Manganese steel is used chiefly for purposes where great endurance is required, such as railroad rails on curves, railroad frogs and crossings, mine-car wheels, burglar-proof safes, and parts of crushing machinery. Manganese steel has also the very great peculiarity of being non-magnetic. This is because the steel has never undergone critical changes on cooling. If, however, it be cooled to the temperature of liquid air, it becomes magnetic, showing that the critical changes have not been entirely suppressed, but have simply been deferred to a lower temperature.

38. Nickel Steel.—The chief purpose of adding nickel to steel is to produce a metal with an extremely fine crystallization. Nickel has the effect of opposing the growth of iron crystals, and a bar of nickel steel containing about 3½ per cent. of nickel, when freshly broken, will show on the fractured surface so fine a degree of crystal as to give the general sheen and appearance of silk. Therefore, nickel steel is not only stronger than ordinary steel, and at the same time ductile, but when the steel is strained and a crack is started, this crack does not spread rapidly from one crystal to another. Consequently, nickel steel stands up better under *fatigue*. The best commercial grade of nickel steel made in large quantities contains about 3½ per cent. of nickel and about .35 per cent. of carbon. Nickel also decreases the

corrodibility of steel and increases its resistance to abrasion. All armor plate for ships contains about $3\frac{1}{2}$ per cent. of nickel steel. High-grade structural steels, as well as parts of costly machinery often have the same amount.

There are many types of nickel steel: one containing 13 per cent. nickel and .55 per cent. carbon, is very hard and has great strength, together with valuable ductility. Steel of 22 per cent. nickel is very resistant to corrosion of water and acidulated waters. When it contains 36 per cent. nickel, it has a very low expansion and contraction with atmospheric changes of temperature. This alloy goes under the trade name of *invar*, because of its invariability. It is used for steel measuring tapes, balance wheels for watches, pendulum rods, etc. Steel with 46 per cent. of nickel is known as *platinite* because, like platinum, it has the same expansion and contraction as glass. It is, therefore, used in the bulbs of incandescent lamps. Nickel steels above 24 per cent. nickel are non-magnetic.

39. These peculiar effects of nickel are due almost entirely to the effect that nickel has upon the critical changes of steel. The more nickel that is added, the lower will be the temperature at which these changes occur, until they are reduced below the atmospheric temperature. The critical changes also have the extraordinary property of irreversibility; this means that the changes take place at an entirely different temperature on heating than that at which the reverse change occurs on cooling. Without a very thorough knowledge of metallography, the theory of nickel-steel qualities cannot be understood.

40. Chrome Steel.—Chromium is commercially added to steel in amounts between .50 per cent and 2 per cent. Chromium has the effect of intensifying the critical changes. Therefore, chromium steel, after rapid cooling from a bright red heat, will be much more intensely hard than steel that is of the same analysis, except for chromium, and treated in the same way. Chromium steels are used wherever an intensification of hardening, or tempering is desired, such as parts of

crushing machinery, burglar-proof safes, springs, cutting tools, files, etc. Balls for ball bearings and rollers for roller bearings are almost always made of a chrome-steel alloy. Chrome steel is harder and stronger than manganese steel, but is not so tough.

41. Vanadium Steel.—Vanadium is added to several types of high-grade steels from the low-nickel alloy steels to some of the most costly alloy steels. It is generally believed that vanadium acts as a scavenger and removes oxygen. It also seems to have a physical effect on alloy steel, because it greatly increases the strength of the material, both when red-hot and when cold. For example, steel cutting tools that do their work so fast that the nose is heated to a dull red heat by the friction of the work perform with much greater endurance when treated with vanadium. In order that the full beneficial effect of the vanadium may be realized, some other alloying element, such as nickel, chromium, etc., must also be present.

In the vanadium treatment it is customary to add ferro-vanadium alloy after all the other recarbonizers have been used. The amount of vanadium added in the alloy should be at least .30 to .40 per cent. of the weight of the steel, and the amount of vanadium left after the treatment should be .15 to .30 per cent of cold steel.

42. Steel for Electromagnets.—Sir Robert A. Hadfield, the inventor of manganese steel, has also invented a steel for electromagnets, which contains about 2.75 per cent. of silicon and the smallest possible amounts of other elements. It is subjected to a double heat treatment; that is to say, it is first heated to a temperature of about 1,950° F. and cooled quickly after which it is heated to a temperature of about 1,400° F. and allowed to cool very slowly. Sometimes it is again reheated to about 1,500° F. and cooled slowly. This steel has the extraordinary property of having a greater magnetic permeability than the purest iron and also having high electric resistance. It is consequently used for parts of motors, dynamos, etc., where the high magnetic force and reduced eddy currents produce high magnetic efficiency.

43. Steel for Permanent Magnets.—The addition of tungsten, chromium, and vanadium to steel of less than 1 per cent. carbon produces a material which, after heat treatment, has a higher magnetic force and a greater permanency than the usual high-carbon steel employed for this purpose.

44. High-Speed Steels.—When steel cutting tools are made to do their work at a very high speed, the resulting friction heats the points to a high temperature. Ordinary tool steel crumbles at this temperature and the limit of the speed of work is dependent upon the strength of the steel at the temperature produced. If tool steel be made to contain about 18 per cent. of tungsten and if the steel be further strengthened by the addition of vanadium, it has great strength at red heat, while at the same time it retains its hardness. It can, therefore, be used for these high-speed cutting tools. The carbon is usually around .65 per cent. or less, and the steel is subjected to drastic heat treatment, in which it is raised to a temperature where the iron oxide begins to melt and drip from the steel, and then is cooled in a blast of cold air.

45. Self-Hardened Steels.—Steel containing more than 5 per cent. tungsten, manganese from 2 to 4 per cent., and carbon above 1.50 per cent., cannot be made soft by any known process. It is, therefore, suitable for cutting tools without any heat treatment whatever. For very heavy work this steel is often used, but it is not a high-speed steel, for it crumbles if the point of the tool is heated to a red heat by a high cutting speed. It will do an enormous amount of work, however, by taking deep cuts and lasts a long time without grinding.

46. Nickel-Chrome Steel.—Steel of very high tensile strength and moderate ductility may be made with 1 to 2 per cent. of nickel and .50 to 1 per cent of chromium. The strength of such steel is increased by heat treatment and especially by double heat treatment. It is used especially for high-grade axles, crank-shafts, etc. It is also customary

to add about $1\frac{1}{2}$ per cent. of chromium to nickel-steel armor plate, to increase its hardness and resistance to the penetration of a projectile. Vanadium is also added customarily to steel to be made into armor plate.

47. Chrome-Vanadium Steel.—Chrome-vanadium steel has somewhat the same properties as chrome-nickel steel, but it is a little easier to make and treat, and has perhaps a greater resistance to dynamic strains. Chrome-vanadium steel is used for the best axles, springs, and other purposes requiring great strength and resistance to sudden shocks and blows, such as parts of automobiles, automobile crank-shafts, etc. The amount of chromium usually varies from .75 to 1.50 per cent. and the vanadium is in accordance with the usual treatment.

EXAMINATION OF THE FINISHED PRODUCT

48. Chemical Examination.—After the steel is finished, it is subjected to examination to ascertain if the desired qualities in chemical composition and physical properties have been reached. Throughout the manufacture of steel the chemical laboratory plays an important part: First, in the selection of proper materials; second, as a guide and check in controlling operations; and, finally, in the analysis of the finished product. Methods of analysis are given fully in *Quantitative Analysis*, and represent the latest accepted methods and those used in practical steel laboratories.

49. Physical Testing.—The steel is subject to various mechanical tests for properties, such as tension, twisting, quenching at redness, and bending, tests of forgeability, etc. Rails and axles are subject to drop tests, that is, the full-sized member (a section of rail) is supported near the ends on solid blocks or foundations, and a weight, or *tup*, dropped midway between the supports. The height of drop and weight of *tup* vary with the section of the member tested and the specifications of the purchaser. Testing of this kind may be regarded as qualitative, so far as measuring the exact

force applied and expressing it in exact quantities is concerned. It is not to be considered of less value or importance for this reason, for it is better adapted to show what the material will do in service. All physical testing is, or should be, made to approximate as closely as possible the actual conditions under which the material is used.

50. Testing Machine.—The simplest conception of a testing machine is to consider it as a weighing machine arranged to register the force required to break or to produce certain effects in the test specimen. It is used to pull test specimens taken from plates, structural material, merchant shapes (rounds, squares, etc.), or cast-steel test bars, etc. Fig. 2 shows one of the standard types of machine of 100,000 pounds capacity. They are made in all sizes up to 3,000,000 pounds capacity, but above 200,000 pounds the machines are mainly for experimental purposes or special work; the 100,000-pound machine is the size commonly used in testing laboratories. The machine is driven by a direct-connected motor or from shafting. Hydraulic testing machines were formerly much used, but now hydraulic power is used only in the case of extremely large machines.

51. The screw machine, Fig. 2, is the one used for testing ordinary sections; in it the strain is applied to the piece through vertical screws, one of which is shown at *a*. One end of the test piece is held in the top, or fixed head *b*, of cast steel, supported on cast-iron columns resting on the heavy iron base or weighing table, which, in turn, rests on hardened-steel knife edges in a series of levers that transmit the strain, as applied by the screws, to the weighing apparatus; the strain is registered by the poise on the beam *c*. The lower end of the test piece is held in the movable or pulling head *d*, which is lowered or raised by the two screws *a*, reaching nearly to the fixed head, passing through two brass nuts fastened in it; the screws pass down to the base of the machine, where they are keyed to main gears by which they are revolved in either direction, raising or lowering the pulling head as desired. Gears controlled by the levers

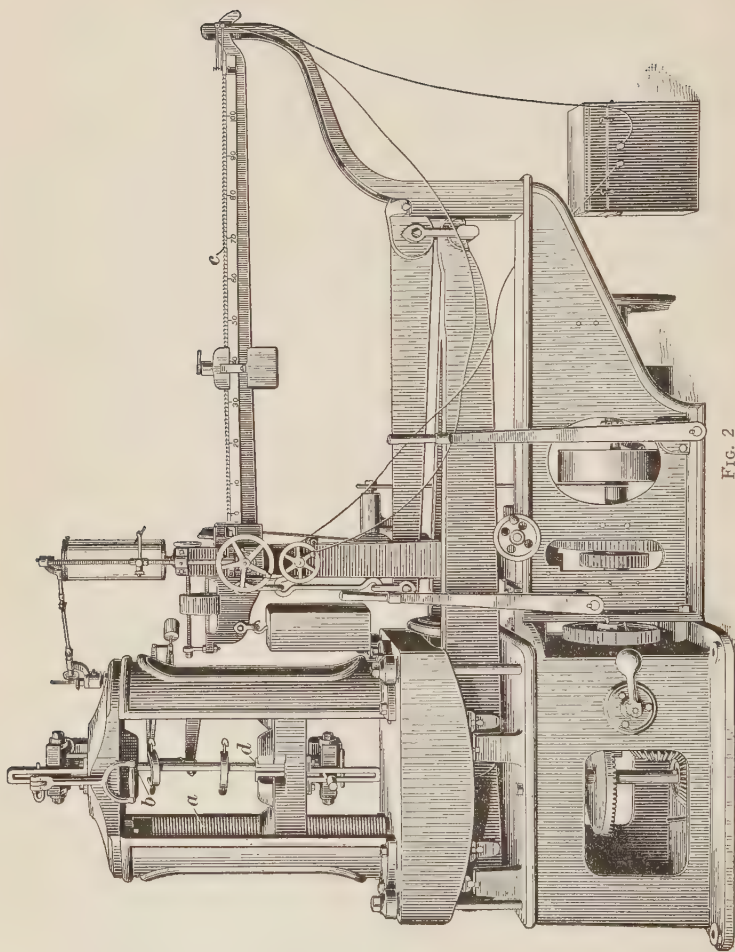


FIG. 2

shown are provided for operating at several different speeds. In both the fixed and pulling heads, holes are cut with sloping sides in which wedges, or *grips*, fit for holding the test piece.

In making a tensile test, the lower, or pulling, head is run up to the proper height to adjust the specimen in the grips, when the screws are reversed and the pulling head starts down on the screws, stretching the piece until it breaks, the upper end being firmly held by the grips of the fixed head. The machine is principally used for making tensile or pulling tests, but may also be used for compression or transverse tests, when the grip lever and hanger on the pulling head are removed, and the specimen placed on the weighing table and the movable head run down on the specimen until crushed or broken, the strain being registered on the beam as in a tensile test.

52. Test Piece.—The standard test piece for most purposes has a gauged length of 8 inches, in which the stretch is measured. Fig. 3 (a)

shows the specimen for plates and structural material for bridges; ships, or buildings; and (b), for cylindrical bars.

The former is cut from the finished plate, beam, etc., the edges

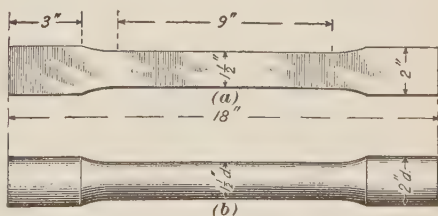


FIG. 3

being reduced as shown; the two opposite sides are the rolled surfaces. In the case of rounds, squares, rods, etc., tests are made whenever possible on full-sized sections as rolled and in a length of 8 inches. For steel castings, forgings, and axles, the test specimen is cut from the product and turned to a diameter of $\frac{1}{2}$ inch by 2 to 4 inches gauged length. It was formerly quite common to forge or roll a small ingot and make the physical test on this; this is objectionable, as heat treatment or work received may be different and give varying results in tests; test specimens are universally taken from the finished material and

tested in as nearly as possible to the natural condition; that is, as produced.

In test pieces that are machined, the opposite sides must be parallel throughout the length of the test section, that is, the length, or a little more, in which measurements are made. Bars, rods, etc., tested in the shape they leave the rolls, without any machining, usually vary but slightly in a length of 8 inches and are calipered in several places and the average taken. It is important that there should be very little variation throughout the length, as it affects the area on which the calculations are based. Measurements of thickness, width, or diameter are made with a micrometer gauge accurate to the one-thousandth of an inch, and from these measurements the area of the cross-section is calculated—which in rectangular sections is merely multiplying the two dimensions together; or in round sections, finding the area of a circle with the diameter given. The elastic limit and tensile strength, as shown on the beam of the machine, are calculated from the area to pounds per square inch, and always so reported.

53. Properties Determined in Testing.—The properties usually determined in testing are: (a) elastic limit, (b) tensile strength, (c) elongation, (d) reduction of area.

The elastic limit is that point at which the metal under strain takes the first appreciable set; or the point at which the steel under strain will not return to its original form and dimensions when the strain is removed. This is by far the most important property, as well as the one observed first in testing. Steel strained beyond its elastic limit is liable to give way under very light loads or much below its original elastic limit; continued strains near the elastic limit may produce the same result. It is determined in testing by *the drop of the beam* in all steel-works laboratories; automatic devices governed by electrical contact are in use to a very limited extent. As the load on the test piece increases, the poise is moved out along the beam to just balance this; the instant the elastic limit is reached there is a

momentary and sudden elongation of the piece and the load on the machine is released to such an extent that the beam drops quickly in its surrounding guard. It remains stationary a number of seconds, but the interval is decided and lasts until the movement of the pulling head catches up with the flow of metal in the test piece. In other words, the metal of the test piece, at the point of elastic limit, travels faster than the pulling head; hence, the drop of the beam corresponds to the elastic limit. The weight shown on the graduated beam is the elastic limit in pounds.

The term *tensile strength* is self-explanatory, and in determining it the stress is applied until the specimen parts. The tensile strength is important in determining the fitness of the steel for given purposes—but less so than the elastic limit.

Elongation is measured for most specimens in a length of 8 inches (2 or 4 inches in castings and forgings). It is determined by placing punch marks the proper distance apart on the surface of the test piece before placing it in the machine; after breaking, the fractured ends are pushed together and the increased distance the punch marks are now apart over the original distance equals the elongation; for example, punch marks measure 10 inches apart after the fracture of an 8-inch test piece, a stretch of 2 inches in 8 inches, or an elongation of 25 per cent.; it is measured to the closest hundredth of an inch.

As the piece stretches, its cross-section is reduced and the point where fracture occurs is drawn down, approaching a conical point more or less. The area of this reduced section, measured at the fracture, compared with the area of the original section, is the *reduction of area* expressed in per cent. of the original area. The elongation and reduction of area are valuable expressions of the elasticity and ductility of the steel. An increase of elastic limit and tensile strength accompanies less elongation and reduction, or the harder steels are stronger, but stretch and reduce less.

54. Effects of Work and Heat on Steel.—The physical properties of steel are greatly affected by the amount of

work done upon it; that is, rolling, forging, pressing, wire drawing, etc.; and the temperature at which the work is done. In general, the more work steel receives, or the greater the reduction from a given section, the higher is the elastic limit and tensile strength, with less stretch; but the ductility (expressed in reduction of area) is not so much affected by treatment above red heat unless there are great variations in heat at the same time.

In plates, with other conditions uniform, the thicker the plate, the lower is the strength, and the less is the stretch. Between a $\frac{1}{4}$ -inch and a $\frac{3}{4}$ -inch plate rolled from the same steel, there may be a difference of 3,000 to 6,000 pounds per square inch in the tensile strength. This difference may be further increased by working at a lower heat, or lessened by rolling hotter. We have, then, increased working adding to the strength, and, in fact, to the good qualities of the steel, if it is done at the proper temperature. Cold working increases the strength, but at the expense of ductility. Either extreme is objectionable, as not developing the desired qualities in the steel.

55. Relation of Chemical Composition to Strength.

Much work has been done by various investigators to establish the relation between the chemical composition and the strength of steel, and various formulas for calculating the strength from the composition have been proposed. Mr. W. R. Webster has conducted the most exhaustive experiments in this direction, and his results in many cases quite closely approach those obtained from the testing machine. With all conditions uniform—the same steel, equal size ingots or slabs, heated to a like temperature, and the amount of reduction in rolling, etc.—the chemical analysis will give the strength very closely. But, owing to variations in mill practice (principally finishing temperature and different amounts of work), some of which cannot always be kept within the close limits desirable, the estimation of strength from analysis may be said to be only an approximation. However, this approaches so nearly the results of tests that it is of great value as a preliminary estimation of the ultimate strength.

ESTIMATED ULTIMATE ST

Carbon	.06	.07	.08	.09	.10	.11	.12	.13	
Phos. .000..	39,550	40,350	41,150	41,950	42,750	43,550	44,350	45,150	4
Phos. .005..	39,950	40,750	41,550	42,400	43,250	44,100	44,950	45,800	4
Phos. .010..	40,350	41,150	41,950	42,850	43,750	44,650	45,550	46,450	4
Phos. .015..	40,750	41,550	42,350	43,300	44,250	45,200	46,150	47,100	4
Phos. .020..	41,150	41,950	42,750	43,750	44,750	45,750	46,750	47,750	4
Phos. .025..	41,550	42,350	43,150	44,200	45,250	46,300	47,350	48,400	4
Phos. .030..	41,950	42,750	43,550	44,650	45,750	46,850	47,950	49,050	5
Phos. .035..	42,350	43,150	43,950	45,100	46,250	47,400	48,550	49,700	5
Phos. .040..	42,750	43,550	44,350	45,550	46,750	47,950	49,150	50,350	5
Phos. .045..	43,150	43,950	44,750	46,000	47,250	48,500	49,750	51,000	5
Phos. .050..	43,550	44,350	45,150	46,450	47,750	49,050	50,350	51,650	5
Phos. .055..	43,950	44,750	45,550	46,900	48,250	49,600	50,950	52,300	5
Phos. .060..	44,350	45,150	45,950	47,350	48,750	50,150	51,550	52,950	5
Phos. .065..	44,750	45,550	46,350	47,800	49,250	50,700	52,150	53,600	5
Phos. .070..	45,150	45,950	46,750	48,250	49,750	51,250	52,750	54,250	5
Phos. .075..	45,550	46,350	47,150	48,700	50,250	51,800	53,350	54,900	5
Phos. .080..	45,950	46,750	47,550	49,150	50,750	52,350	53,950	55,500	5
Phos. .085..	46,350	47,150	47,950	49,600	51,250	52,900	54,550	56,200	5
Phos. .090..	46,750	47,550	48,350	50,050	51,750	53,450	55,150	56,850	5
Phos. .095..	47,150	47,950	48,750	50,500	52,250	54,000	55,750	57,500	5
Phos. .100..	47,550	48,350	49,150	50,950	52,750	54,550	56,350	58,150	5
.001 Phos. . .	80	80	80	90	100	110	120	130	

ADDITIONS FOR MANGANESE

Mn	Lb.	Mn	Lb.	Mn	Lb.	Mn	Lb.	Mn	Lb.	
		.210	5,020	.310	7,080	.410	8,740	.510	10,000	.
		.215	5,130	.315	7,170	.415	8,810	.515	10,050	.
		.220	5,240	.320	7,260	.420	8,880	.520	10,100	.
		.225	5,350	.325	7,350	.425	8,950	.525	10,150	.
		.230	5,460	.330	7,440	.430	9,020	.530	10,200	.
		.235	5,570	.335	7,530	.435	9,090	.535	10,250	.
		.240	5,680	.340	7,620	.440	9,160	.540	10,300	.
		.245	5,790	.345	7,710	.445	9,230	.545	10,350	.
.150	3,600	.250	5,900	.350	7,800	.450	9,300	.550	10,400	.
.155	3,720	.255	6,000	.355	7,880	.455	9,360	.555	10,450	.
.160	3,840	.260	6,100	.360	7,960	.460	9,420	.560	10,500	.
.165	3,960	.265	6,200	.365	8,040	.465	9,480	.565	10,550	.
.170	4,080	.270	6,300	.370	8,120	.470	9,540	.570	10,600	.
.175	4,200	.275	6,400	.375	8,200	.475	9,600	.575	10,650	.
.180	4,320	.280	6,500	.380	8,280	.480	9,660	.580	10,700	.
.185	4,440	.285	6,600	.385	8,360	.485	9,720	.585	10,750	.
.190	4,560	.290	6,700	.390	8,440	.490	9,780	.590	10,800	.
.195	4,680	.295	6,800	.395	8,520	.495	9,840	.595	10,850	.
.200	4,800	.300	6,900	.400	8,600	.500	9,900	.600	10,900	.
.205	4,920	.305	6,990	.405	8,670	.505	9,950	.605	10,950	.

IV
 5, POUNDS PER SQUARE INCH

	.16	.17	.18	.19	.20	.21	.22	.23	.24	.25
50	47,550	48,350	49,150	49,950	50,750	51,550	52,350	53,150	53,950	54,750
00	48,300	49,100	49,900	50,700	51,500	52,300	53,100	53,900	54,700	55,500
50	49,050	49,850	50,650	51,450	52,250	53,050	53,850	54,650	55,450	56,250
00	49,800	50,600	51,400	52,200	53,000	53,800	54,600	55,400	56,200	57,000
50	50,550	51,350	52,150	52,950	53,750	54,550	55,350	56,150	56,950	57,750
00	51,300	52,100	52,900	53,700	54,500	55,300	56,100	56,900	57,700	58,500
50	52,050	52,850	53,650	54,450	55,250	56,050	56,850	57,650	58,450	59,250
00	52,800	53,600	54,400	55,200	56,000	56,800	57,600	58,400	59,200	60,000
50	53,550	54,350	55,150	55,950	56,750	57,550	58,350	59,150	59,950	60,750
00	54,300	55,100	55,900	56,700	57,500	58,300	59,100	59,900	60,700	61,500
50	55,050	55,850	56,650	57,450	58,250	59,050	59,850	60,650	61,450	62,250
00	55,800	56,600	57,400	58,200	59,000	59,800	60,600	61,400	62,200	63,000
50	56,550	57,350	58,150	58,950	59,750	60,550	61,350	62,150	62,950	63,750
00	57,300	58,100	58,900	59,700	60,500	61,300	62,100	62,900	63,700	64,500
50	58,050	58,850	59,650	60,450	61,250	62,050	62,850	63,650	64,450	65,250
00	58,800	59,600	60,400	61,200	62,000	62,800	63,600	64,400	65,200	66,000
50	59,550	60,350	61,150	61,950	62,750	63,550	64,350	65,150	65,950	66,750
00	60,300	61,100	61,900	62,700	63,500	64,300	65,100	65,900	66,700	67,500
50	61,050	61,850	62,650	63,450	64,250	65,050	65,850	66,650	67,450	68,250
00	61,800	62,600	63,400	64,200	65,000	65,800	66,600	67,400	68,200	69,000
50	62,550	63,350	64,150	64,950	65,750	66,550	67,350	68,150	68,950	69,750
	150	150	150	150	150	150	150	150	150	150

ADDITIONS FOR SULPHUR

S	.0	.001	.002	.003	.004	.005	.006	.007	.008	.009
.00	000	50	100	150	200	250	300	350	400	450
.01	500	550	600	650	700	750	800	850	900	950
.02	1,000	1,050	1,100	1,150	1,200	1,250	1,300	1,350	1,400	1,450
.03	1,500	1,550	1,600	1,650	1,700	1,750	1,800	1,850	1,900	1,950
.04	2,000	2,050	2,100	2,150	2,200	2,250	2,300	2,350	2,400	2,450
.05	2,500	2,550	2,600	2,650	2,700	2,750	2,800	2,850	2,900	2,950
.06	3,000	3,050	3,100	3,150	3,200	3,250	3,300	3,350	3,400	3,450
.07	3,500	3,550	3,600	3,650	3,700	3,750	3,800	3,850	3,900	3,950

Plates	Up to 70 Inches in Width	Over 70 Inches in Width
$\frac{3}{4}$ inch thick.....	— 2,000 lb.	— 1,000 lb.
$\frac{1}{16}$ inch thick.....	— 1,750 lb.	— 750 lb.
$\frac{1}{8}$ inch thick.....	— 1,500 lb.	— 500 lb.
$\frac{9}{16}$ inch thick.....	— 1,250 lb.	— 250 lb.
$\frac{1}{2}$ inch thick.....	— 1,000 lb.	± 0 lb.
$\frac{7}{8}$ inch thick.....	— 500 lb.	+ 500 lb.
$\frac{8}{8}$ inch thick.....	± 0 lb.	+ 1,000 lb.
$\frac{5}{16}$ inch thick.....	+ 3,000 lb.	+ 4,000 lb.

Table IV is based on Webster's results, and from it the approximate ultimate strength can be found. It is worked out for the elements, carbon (up to .25 per cent.), phosphorus, manganese, and sulphur (in amounts usually present), with corrections for different widths and thicknesses. A brief study of the table will show the manner of applying it. The example given herewith illustrates it:

EXAMPLE.—A given specimen analyzes: carbon .21 per cent., phosphorus .035 per cent., sulphur .032 per cent., manganese .36 per cent. The plate is 80 inches wide and $\frac{9}{16}$ inch thick. Finding the carbon in the upper horizontal line of Table IV, and going down this column until opposite per cent. phosphorus (left-hand vertical column), we find 56,800 pounds per square inch as the strength for .21 per cent. carbon and .035 per cent. phosphorus. The addition for .032 per cent. sulphur is 1,600 pounds; for .36 per cent. manganese, 7,960 pounds; an 80-inch plate $\frac{9}{16}$ inch thick calls for a deduction of 250 pounds. We now have $[56,800(C+P)+1,600 S+7,960 Mn]-250$, or 66,110 pounds, as the ultimate strength per square inch. In using the table, the differences in strength due to the varying temperature and the rolling must not be forgotten, and as these cannot be allowed for, the results from calculation are always liable to differ from those obtained by pulling specimens in the testing machine.

56. Results in Physical Testing.—Table V gives the composition, together with the results, obtained in testing a number of steels of varying carbon percentages.

Table VI shows a record of physical tests, with the measurements, results, etc.

Numbers 9 and 10 of the table are steel castings, pulled in a length of 2 inches, and turned to the diameter shown.

SIZE AND RELATION OF MICROSCOPIC CONSTITUENTS

57. Metallography.—Next to chemical and physical examination, the study of the microscopic constituents in iron and steel, and their size and relations, is the most important source of information as to the quality of the material, or the cause of its failure in service, or its unusual excellence. Pig iron has the following constituents: Ferrite, which is theoretically pure iron; cementite, the carbide of iron; graphite,

TABLE V
COMPOSITION AND RESULTS OF TESTING A NUMBER OF STEELS OF VARYING CARBON PERCENTAGES

Number of Test	Chemical Analysis				Physical Qualities			
	Carbon. Per Cent.	Manganese. Per Cent.	Phos- phorus. Per Cent.	Sulphur. Per Cent.	Elastic Limit. Pounds.	Ultimate Strength. Pounds	Elongation in 8 Inches. Per Cent.	Reduction of Area. Per Cent.
1	.13	.19	.045	.029	28,500	52,000	34.30	
2	.20	.40	.010	.028	34,500	60,240	26.00	56.90
3	.16	.38	.008	.031	30,200	57,400	29.00	59.60
4	.25	.41	.018	.024	35,600	62,880	23.00	43.20
5	.40	.12	.032	.006	50,743	71,300	21.67	
6	.64	.05	.007	.005	50,000	94,500	2.75	
7	.50	.33	.016	.010	63,560	84,200	25.00	29.91
8	.96	.24	.008	.015	65,000	124,800	3.75	
9	.10	.48	.100	.056	36,200	67,800	21.50	52.00
10	.10	.42	.095	.062	35,600	62,400	20.25	44.60

TABLE VI
RECORD OF PHYSICAL TESTS

Chemical Analysis				Measurements and Physical Results												
C Per Cent.	Mn Per Cent.	S Per Cent.	P Per Cent.	Original Dimensions			Elastic Limit		Tensile Strength		Elongation		Dimensions After Fracture			Reduction of Area, Per Cent.
				Breadth, Inches	Thickness, Inches	Area, Square Inches	Pounds	Pounds per Square Inch	Pounds	Pounds per Square Inch	In 8 Inches	Per Cent.	Breadth, Inches	Thickness, Inches	Area, Square Inches	
.20	.38	.032	.009	1.005	.630	.6332	21,900	34,590	31,300	49,440	2.44	30.50	.665	.370	.2460	61.1
.23	.42	.030	.023	1.285	.377	.4844	18,000	37,160	32,100	66,260	2.20	27.50	.960	.220	.2112	55.0
.21	.39	.024	.025	1.295	.380	.4921	18,600	37,800	31,800	64,640	2.10	26.25	.950	.210	.1995	59.5
.15	.41	.022	.012	1.010	.728	.7353	26,600	36,180	45,700	62,150	2.00	25.00	.730	.540	.3942	46.4
.19	.39	.022	.016	1.010	.506	.5110	18,900	36,980	28,400	55,580	2.48	31.00	.660	.270	.1782	65.1
.19	.38	.019	.021	1.345	.370	.4977	19,000	38,180	34,400	69,120	1.64	20.50	1.120	.280	.3136	37.1
.10	.48	.055	.100	1.150	.162	.1863	6,780	36,400	11,500	61,720	1.40	17.50				56.0
.08	.44	.060	.096	1.150 <i>Dia.</i>	.162	.1863	6,670	35,800	11,300	60,660	1.56	19.50	<i>Dia.</i>			
.28				.498		.1948	7,210	37,010	13,900	71,360	.31	15.50	.429		.1445	25.8
.24				.798		.5001	17,100	34,790	34,700	69,380	.36	18.00	.667		.3494	30.1

Per Cent.

Steel of .85 to .90 per cent. carbon, will be composed entirely of pearlite. This steel, because of its fine state of crystallization, is normally the strongest carbon steel that can be made. The large crystals of ferrite which form while steel is cooling between the temperatures indicated by the lines *GoS* and *Ps* in Fig. 4, make it a weaker material to resist strain than one in which the crystals are very small and intimately mixed. Likewise, the very large crystals of cementite which normally form when steel cools between the temperature indicated by the lines *SEa* and *SK'*, make it both very weak and very brittle.

Rail steel, containing, say, .60 per cent. of carbon, will consist of crystals of pearlite surrounded by envelopes of ferrite.

High-carbon steel will consist of pearlite crystals in which are enclosed thin plates of brittle cementite crystals.

58. Microscopy.—The crystals of ferrite, pearlite, etc., are much too small to be observed by the unaided eye; they must be magnified by a microscope, sometimes to 1,000 or 1,500 diameters, to identify them, and to get a quantitative estimate of their relative size, although coarse-crystal steel and fine-crystal steel may be recognized by the eye alone. Every steel expert knows how important to the quality of the steel the size of its crystals is. The study of the constitution of steel aided by microscopic examination, has produced a marvelous evolution and revolution in our knowledge of the characteristics of the material, the effect of different elements, of heat treatment, of rolling, forging, etc. In this discussion the use of Fig. 4 has been the most powerful factor in clarifying our ideas.

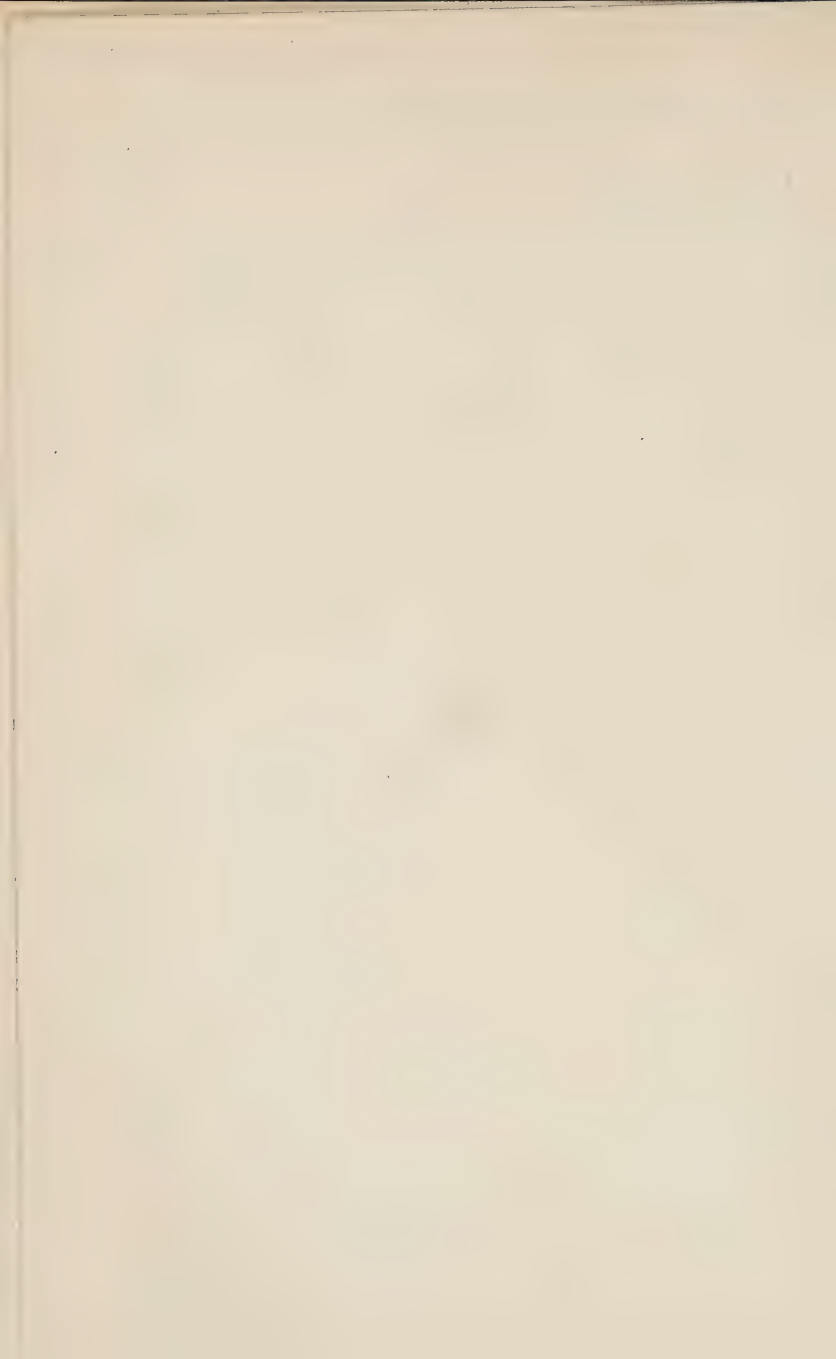
59. Practical Use of Equilibrium Diagram.—The study of the nature of steel, based on the freezing and decomposition curves, as shown in the equilibrium diagram, Fig. 4, is much too complicated to be explained in the space that can be here used. It may be said, however, that all steel having a percentage of carbon that places it to the left of

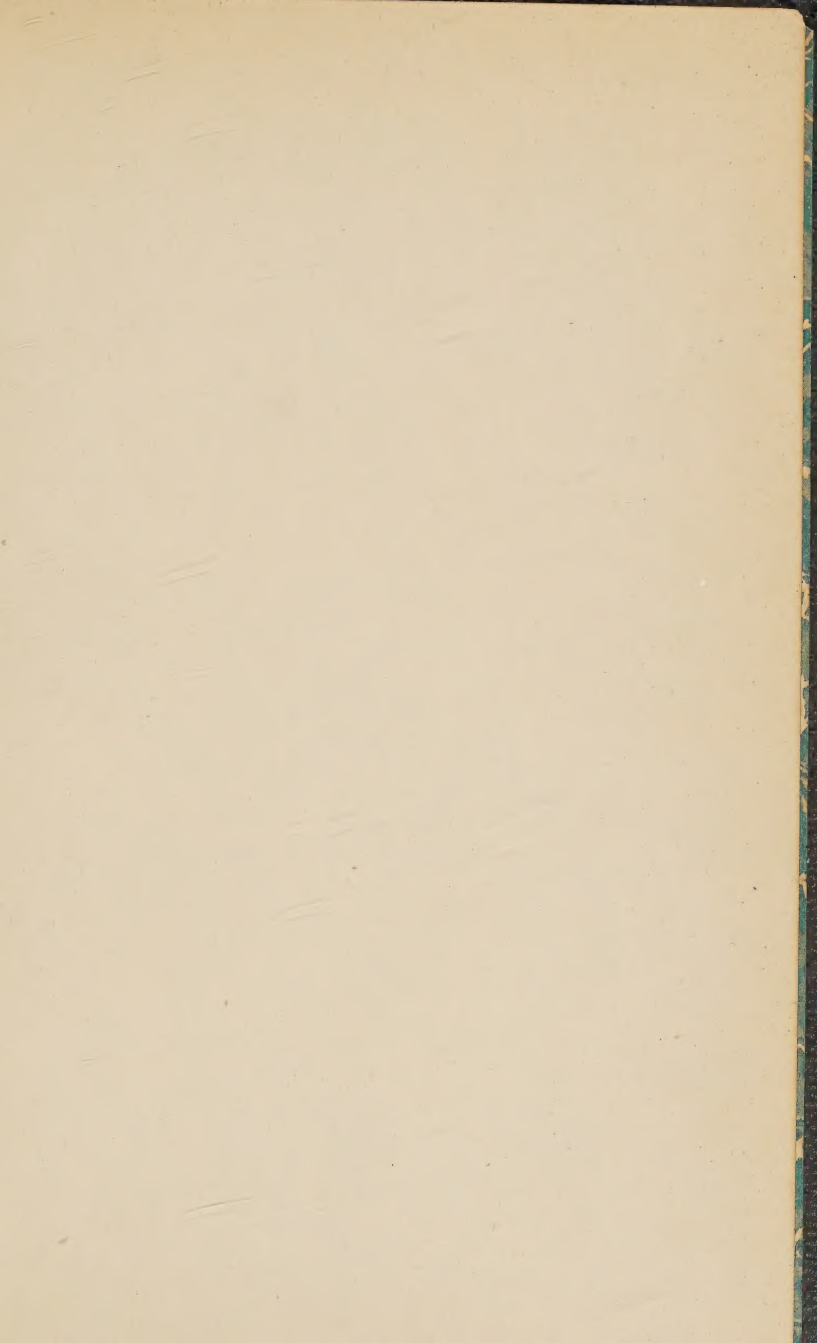
point *S* in Fig. 4 will consist of ferrite and pearlite; all to the right of that point will contain pearlite and cementite; and the steel of about .85 per cent of carbon, just at the point *s*, will consist of 100 per cent. pearlite. Let us also consider heat treatment: Assume a steel of about .35 per cent. carbon, heated to a temperature of 1,472 ° F.; this will be located at the point *h* in Fig. 4. It will consist of a solid solution of iron and carbon; as it slowly cools, it will, after the temperature crosses the line *Go*, begin to deposit crystals of ferrite, which are born out of the solid solution. But, when the temperature crosses the line *PS*, the solid solution decomposes completely, and all that is left over and above the ferrite crystals separated out, will break up into microscopic crystals of pearlite; that is, an intimate mixture of crystals of ferrite with crystals of cementite. If now, instead of cooling this steel slowly, it is plunged into water, or iced brine, or otherwise rapidly cooled from the temperature of 1,472° F., it would attain a black heat so rapidly that the changes just described could not take place in their entirety. The first result would be that the crystals of ferrite (to the extent to which they could separate out in the limited time) would be small crystals instead of large crystals. This would make the steel stronger. The second result would be that the solid solution would not have time to decompose at the line *PS*; only a partial decomposition would take place, and thus the steel would be in a state of strain, which would make it harder and less ductile. Unfortunately there is not space here to discuss the very interesting details affecting this result.

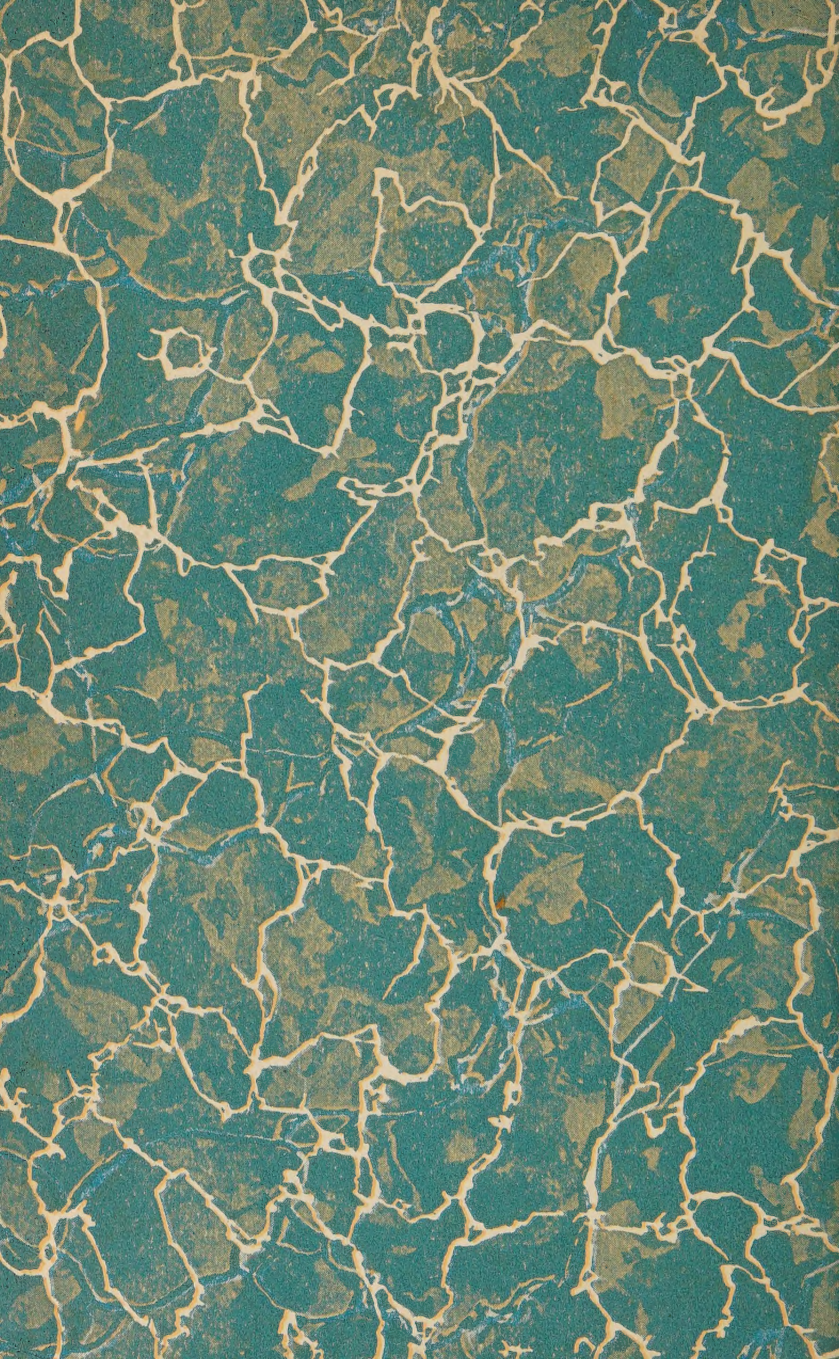
Very low carbon steel, in cooling from near the point *G* to below the line *PS*, will form large crystals of ferrite; this will make the steel low in strength. If now, it is cooled rapidly from the high temperature, the crystals will be smaller and the steel will be greatly increased in strength without much decrease in ductility. A second heating, never going as high as the line *PS*, will relieve the strains of the steel and decrease its hardness without making the crystals large. The crystals grow large in size only when the steel is heated above the line *PSK'*.

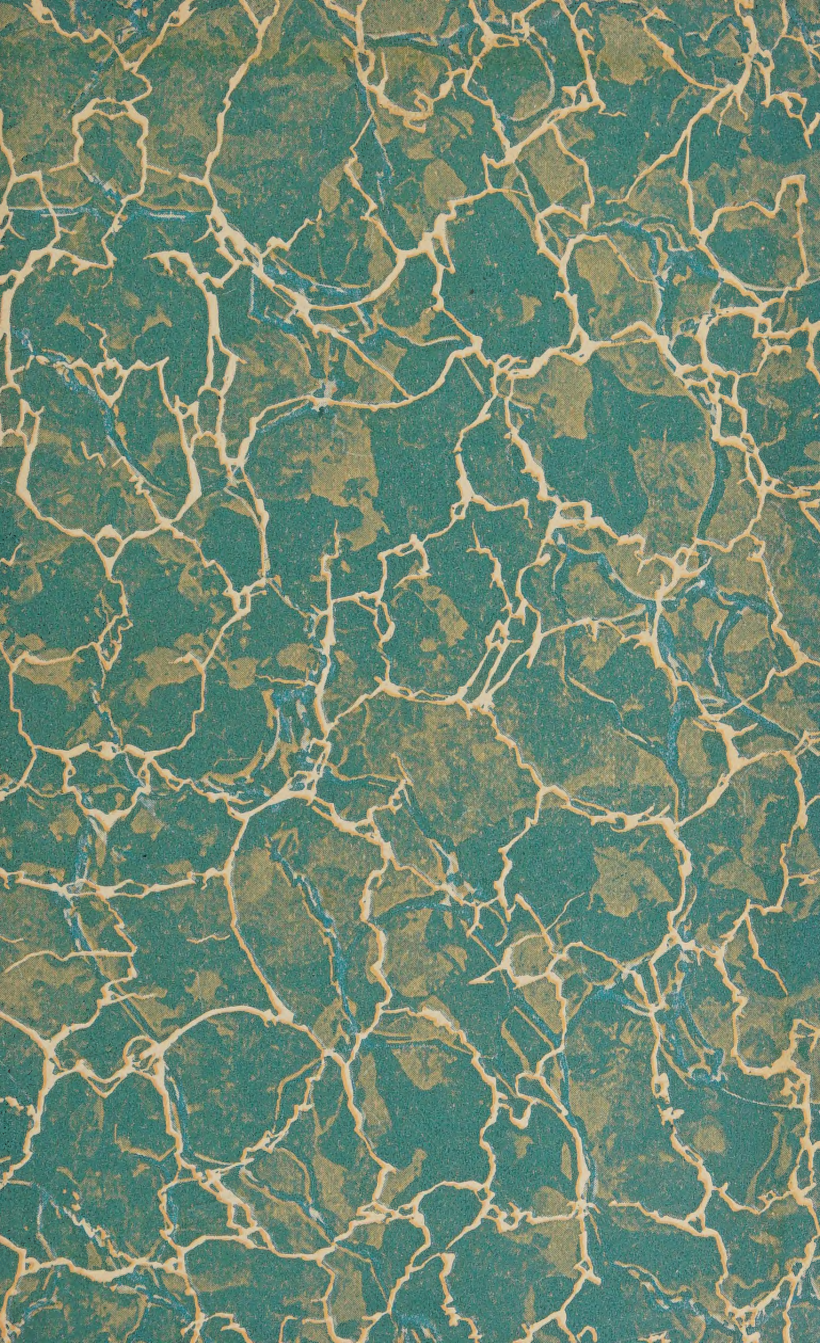
60. Effects of Alloying Elements.—Nickel has the effect of reducing the formation of large crystals at temperatures higher than those indicated by the line PSK' . It also changes the positions of all the lines in Fig. 4. Manganese has an effect more powerful than nickel in changing the position of the lines. Chromium increases the effect of rapid cooling, by suppressing the changes which normally occur as indicated in Fig. 4, thus intensifying the hardening effect of rapid cooling. Silicon and sulphur affect the changes which occur in the freezing of iron and steel. It is by means of these metalloids, therefore, that either white pig iron or gray pig iron is produced.

61. Large Crystallization in Steel.—The higher steel is heated above the temperature indicated by the line PSK' , the larger will be the size of the crystals formed, and the lower the qualities corresponding, because large crystals decrease both strength and ductility. Steel that has been rendered coarse-crystallized may be restored to good quality by reheating to a temperature just above the lines $GoSK'$, provided the coarse crystallization is not too great. Rolling, forging, and hydraulic pressing above a red heat, that is, above the lines PSK' , will also break up big crystals, provided the work is continued down to near the temperature of this line that is, about $1,292^{\circ}$ F. If the work is at a higher temperature, the crystals will grow to a size normal to that temperature. That is why the finishing temperature in rolling, etc., is so important to the quality of steel. It is also the reason why, in the annealing of steel, especially castings, temperatures too far above the lines $GoSK'$ must not be employed. The same is true of the hardening of tool steels; they must not be heated more than a very few degrees above the line SK' .











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